THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Doctor of Philosophy (Entomology)

DEGREE

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FIELD	**DEPARTMENT**

TITLE: Biological Study of Larval Parasitoid, *Asecodes hispinarum* Bouček (Hymenoptera: Eulophidae) and Pest Management Program for Major Insect Pests of Coconut in a Golf Course

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THESIS

BIOLOGICAL STUDY OF LARVAL PARASITOID, *Asecodes hispinarum* Bouček (Hymenoptera: Eulophidae) AND PEST MANAGEMENT PROGRAM FOR MAJOR INSECT PESTS OF COCONUT IN A GOLF COURSE

THITRAPORN PUNDEE

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Doctor of Philosophy (Entomology)
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Thitraporn Pundee 2009: Biological Study of Larval Parasitoid, *Asecodes hispinarum* Bouček (Hymenoptera: Eulophidae) and Pest Management Program for Major Insect Pests of Coconut in a Golf Course. Doctor of Philosophy (Ento.mology), Major Field: Entomology, Department of Entomology. Thesis Advisor: Associate Professor Surachate Jamornmarn, Ph.D. 136 pages.

Study on biology and mass rearing of larval parasitoid, *Asecodes hispinarum* Bouček were conducted under laboratory conditions (25±2°C and 70±10% RH) with natural lighting and temperature-controlled incubator at the Plant Protection Research and Development Office in Bangkok, during July 2006-December 2007. With four levels of temperature at 22, 25, 28 and 31°C were tested; the results showed that at 22°C the adult longevity of *A. hispinarum* was longest. Females lived longer than males; however, an increase of temperature leads to decrease longevity. Longevity of male and female parasitoids fed with honey at 22°C averaged 3.35±1.34 and 4.90±1.36 days, respectively. For study host specificity testing, it was found that the *A. hispinarum* could parasitize the larvae of *Plesispa reichei* Chapuis, but the quality of mummified larvae was lower than reared on *Brontispa longissima* Gestro. Females of *A. hispinarum* laid an average of 47.29 eggs during their lifetime, with range of 20-77 eggs.

Testing of *A. hispinarum* under laboratory conditions, optimal time for parasitization was at 24 hours. Optimum densities of female for parasitization on mass rearing of *A. hispinarum* were 40 and 60 females per box ($14\times 10\times 6$ cm^3) per 20 on *B. longissima*. At 25°C showed the highest percentage of emergence of *A. hispinarum,* while at 31°C were critical for all development life cycle, parasitization and emergence. *A. hispinarum* had the longest mean developmental time (23.8 days) at 22°C and the shortest (16.5 day) at 28°C. *A. hispinarum* was able to parasitized at all larval instars of *B. longissima*; however, the 3rd and 4th instars larvae of *B. longissima* showed the best host stages for mass production. *A. hispinarum* reared on the larvae of *B. longissima* feeding on coconut, *Cocos nucifera* L. and typhus, *Typha angustifolia* L. leaves was not different on percentage of parasitization, percentage of emergence and percentage of female.

Implementation of Integrated Pest Management at Panya Indra golf course, Bangkok, during January 2007-March 2008 to major insect pests of coconut; the coconut hispine beetle, *B. longissima*, red palm weevil, *Rhynchophorus ferrugineus* Oliver and rhinoceros beetle, *Oryctes rhinoceros* L. Mummified larvae of *B. longissima* were released at average 246 mummies per month during January to December 2007 with total were 2,950 mummies. The first mummified larvae were established and found in five months after released. The mummified larvae were collected in June, August and November, and percentages of parasitization were calculated at 13.48%, 8.58% and 14.08%, respectively. Coconut trees at golf course showed clear signs of recovery with green shoots on November. Red palm weevil was applied by cultural control and pheromone traps. Adult of red palm weevil was counted in pheromone traps a month intervals, during April 2007 to March 2008. Twenty one of coconut trees destroyed by red palm weevil was cut during this study for reduce the source of food by rhinoceros beetle. Ten pheromone traps were set around the area of the golf course. Total of 26 red palm weevils were caught with male and female were 8 and 18 beetles, respectively. Damaged palms by the red palm weevil disappeared. Entomophathogenic fungus *(Metarhizium anisopliae)* and pheromone traps of rhinoceros beetle was applied. Duration of experiment of the rhinoceros beetle was carried out first and ends as same as red palm weevil. Maximum infected larvae by *M. anisopliae* in manure pits was found on June to November but the least was in March to April. *M. anisopliae* showed a significant negative relationship on high temperature and low humidity. Pheromone traps were set totally 16 traps. Total of 718 rhinoceros beetle adults were caught. The adults of male and female caught were 130 beetles and 588. It concluded that the coconut palms in the Panya Indra golf course were recovery from the damage of the coconut hispine beetle and the red palm weevil at the end of study. Whereas it was not cleared on the sign by the rhinoceros beetle since there were migrate of the rhinoceros beetle from outside of the golf course.

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Student's signature Thesis Advisor's signature

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I am very much pleased to express the deepest gratitude and special thanks to Assoc. Prof. Dr. Surachate Jamornmarn, my thesis advisor for his guidance, advice and encouragement throughout the course of this study. I wish to extend sincere thanks and appreciation to all member of the thesis committee for their kind advice, technical guidance, material support and suggestions during the course of this study.

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Thitraporn Pundee
March 2009

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LIST OF ABBREVIATIONS

%	=	percentage
^{o}C	=	degree of celsius
avg.	=	average
cm	=	centimeter
df	=	degree of freedom
diam.	=	diameter
entomol	=	entomology
et.al	=	et. alii. (and others)
etc.	=	et cetera
g	=	gram
ha.	=	hectare
hrs	=	hours
i.e.	=	id est
in.	=	inch
IPM	=	Integrated Pest Management
Jour., J.	=	journal
L:D	=	a light-dark cycle
m.	=	meter
mm.	=	millimeter
n, no.	=	number
P	=	probability
p., pp.		page
RH	=	relative humidity
SD	=	standard deviation
THB	=	Thai bath
t-tests	=	two-way comparisons
w/v	=	weight per volume

BIOLOGICAL STUDY OF LARVAL PARASITOID, *Asecodes hispinarum* Bouček (Hymenoptera: Eulophidae) AND PEST MANAGEMENT PROGRAM FOR MAJOR INSECT PESTS OF COCONUT IN A GOLF COURSE

INTRODUCTION

The coconut palm, *Cocos nucifera* L., is a member of the family Arecaceae (palm family). All parts of the coconut palm are useful and the trees have a comparatively high yield (up to 75 fruits per year per plant). Therefore, it has significant economic value (Wales and Sanger, 2001). The coconut palm is a versatile plant with a variety of uses. Every part of it is useful to mankind in one form or another because it supplies food, drink, shelter and also raw materials for a number of industries (Panwar, 1990). It is one of the ten most useful trees in the world, providing food for millions of people, especially in the tropics (Duke, 1972). Coconut is highly nutritious and rich in fiber, vitamins, and minerals. It is classified as a "functional food" because it provides many health benefits beyond its nutritional content. Coconut oil is of special interest because it possesses healing properties far beyond those of any other dietary oils and is extensively used in traditional medicine among Asian and Pacific populations. Pacific Islanders consider coconut oil to be the cure for all illnesses. The coconut palm is so highly valued by them as both a source of food and medicine (Coconut Research Center, 2004). Coconut plays a direct major role in the economies of many countries in the Asia and Pacific region directly by providing food and income from coconut products, and indirectly as an important component of the landscape where tourism plays a key role in the economy.

The coconut palm is susceptible to the attack by a large number of pests of major and minor importance. All of these are capable in causing considerable damage to the coconut palm resulting in reducing yields (Thampan, 1975). At least 751 insect pests of coconuts have been recorded around the world. These pests attack the leaves, stems, flowers, nuts and roots of the coconut plant. Of all 751, Coleoptera is the most numerous, totaling 323 species (Child, 1974). Most species of the beetles that feed on leaves of higher plants belong to either of the two largest families of the beetles, Curculionidae and Chrysomelidae, both of which are entirely phytophagous. Some species of Curculionidae and Scarabaeidae are borers in palm buds, which results in damage to the fronds as they open (Howard *et al*., 2001). The main pests of coconut palms are the coconut hispine beetle, red palm weevil and rhinoceros beetle that cause enormous damage to various cultivated coconut palm. Use of chemical pesticides to control the outbreak of coconut hispine beetle and reduce the rate of spread is often costly, ineffective and unsustainable.

The coconut hispine beetle, *Brontispa longissima* Gestro, is one of the most serious pests of coconut in Asia and the Pacific. Both larvae and adults feed on tissues of developing, unopened leaves of the trees. The beetle can cause significant production losses, and high infestation levels may result in tree death (Liebregts and Champman, 2004). The red palm weevil, *Rhynchophorus ferrugineus* Oliver, is the most dreaded pest of young palms. The pest is known to cause severe damage to coconuts in South East Asia and also to date palms in the Middle East. As the red palm weevil is a concealed borer, detecting infested palms becomes extremely difficult. If infestation is not detected early, infested palms often die (Abraham *et al*., 1998). The rhinoceros beetle, *Oryctes rhinoceros* L., is a serious pest of coconut and oil palms in South East Asia and in some Pacific Islands. The adult feeds on the growing tips of the palm producing eventually ragged appearance of mature palm leaves. A severely attacked palm will die or be damaged by secondary-attack pests (Renou e*t al*., 1998).

In Thailand, there is a new serious invasive pest of the coconut palm i.e. the coconut hispine beetle. It is an exotic pest of coconut and ornamental palms. It is believed to be endemic to Indonesia and possibly also to Malaysia, Papua New Guinea and the Solomon Islands. In the twentieth century, the beetle was accidentally introduced into several other countries of Southeast Asia and the Pacific. However, this invasive pest is new to continental Southeast Asia where, in the absence of natural enemies, it is rapidly spreading and causing massive damage (Food and

Agriculture Organization [FAO], 2004). It was first found in Narathiwat Province, the border area near Malaysia, in 2000. Heavy infestation was first reported in February 2004 in Southern provinces including Surat Thani (Samui Island and Pha-ngan Island) and Prachuap Khiri Khan. The beetles attack the central leaf bud, and the young leaves of the coconut palm (Sindhusake and Winotai, 2004). The fruits are particularly susceptible when they are in contact with one another. Dwarf palms are injured most severely, and may suffer a very heavy loss of crops (Howard *et al*., 2001 *cited* Bondar, 1940). It is also a treat to the tourist industry of Samui Island and Pha-ngan Island. The impact of the damage is very significant. Besides high losses in coconut production and high number of young palms mortality, an infested country also have to spend more money for chemical control. Importantly, the use of pesticides also raises serious concerns about the health risks of the farmers, their families and consumers (Youngfan, 2004). Biological control by using parasitoid, predator and entomopathogen has a good chance to suppress population of coconut hispine beetle in the field. Biological control would decrease the use of insecticides. Therefore it has a good impact to the environment. Additionally, this practice has long-term impact to depress or manage the pest population on coconut plantation in low level of palm damage (Meldy *et al*., 2004). The FAO Regional Office for Asia and Pacific is implementing technical cooperation programme projects on Integrated Pest Management (IPM) of coconut hispine beetle in Vietnam, Nauru, Maldives, Thailand and Hainan Island of China. The main thrust is classical biological control. The larval parasitoid, *Asecodes hispinarum* Bouček was collected in Samoa in 2003 and introduced, reared and released in Vietnam, Maldives and Nauru to combat the beetle. The parasitoid was established in all the three countries, with promising prospects for achieving control of the beetle. Initial results from Vietnam confirmed the establishment of the parasitoid in provinces where it was released and observations at and near release sites indicated that beetle damage had been reduced considerably. Surveys have shown that the dispersal rate of the parasitoid was rapid. In Maldives and Nauru, field establishment of the parasitoid was confirmed after two and five months after initial field releases in February and November, respectively (Rethinam and Singh, 2005). However, the pests of coconut palm can multiply uninterruptedly all the year round with the result that the coconut plantations are often seriously damage. Other important pests of coconut palm beside coconut hispine beetle are red palm weevil and rhinoceros beetle in coconut palm plantations. The beetles are the most damaging insects to coconut palm. The most important management option to control the coconut insects were the use of IPM.

Coconut palms are usually planted for ornamental plants in many golf courses around Bangkok Metropolitan and its neighboring provinces. The coconut hispine beetle has been obvious damaged since 2005. To play IPM in golf course for this study, the other major insect pests as red palm weevil and rhinoceros beetle were included in the management program. The management program should yield the maximum results, at the lowest cost, with a minimum of environment disruption.

OBJECTIVES

The objectives of this study are as follows:

1. To study on mass rearing and biological studies of *Asecodes hispinarum* Bouček parasitoid of coconut hispine beetle, *Brontispa longissima* Gestro.

2. Feasibility study of biological control of *A. hispinarum* in laboratory condition.

3. To study the feasibility use of coconut insect pest management on major coconut insect in golf course.

LITERATURE REVIEW

1. Coconut palm

Coconut palm is supposed to have a number of uses and almost as many names. Scientifically, there is only one species of coconut (*Cocos nucifera* L.) with two plant habits (Tall and Dwarf) and three basic color forms (yellow, red and green) (Hugh, 1993). The coconut palms and its fruits are regarded as the most important plant to humans around the world (Child, 1974). Among its most important uses coconut is a food source, provides supplement for body fluids and minerals (Woodroof, 1970). Coconuts are grown in all tropical regions around the world, where the temperature, humidity, soil and elevation are suitable. They are grown within a few degrees of the equator; within 180 m. of sea level; on loose, sandy soil; with high mean temperatures and relative humidities. Such conditions are found on tropical islands and along shores of tropical continents. Coconut growing on the temperature should range from 24 to 30^{o}C and never less than 20^{o}C and the rainfall should range from 60-80 in. per year evenly distributed, and never less than 40 in. per year. Trees growing near the coast or over a high water table thrive on lighter rainfall than those growing on higher elevation (Aten *et al*., 1985).

The coconut palm is romantically associated with beautiful tropical beaches and is the most widespread and most easily recognizable of all palm trees. From the mid-19th century until the 1960s, the dried kernel of the coconut, copra, became the most important source of vegetable oil in international markets (Janick and Paull, 2008). The coconut palm is one of the most important sources of vegetable oil in the world. With oil yield up to 65%, copra, the main product of the palm is perhaps the richest material for vegetable oil extraction. Oil palm kernels yield only 46%, shelled groundnuts 44% and soyabeans 16-18%. Copra and coconut oil are traditional commodities in the world markets for oilseeds, oils and fats. Total world exports of copra and coconut oil are estimated at about 1.45 million tones (MT) of oil equivalent, which represent a share of approximately 10-11% of the world's total export trade in oils and fats (Thampan, 1975). Coconut palms provide many basic products ranging from fresh drink, oil, fiber, oleochemicals and household utensils to timber and building materials. They play an important role in the environment, health, food security and livelihood of many people in the region that it is called “The Tree of Life” (Figure 1). There, coconut is not only an important local food crop, but is perhaps even more important for tourism industry (Luigi, 2005).

In Thailand, coconut palm is one of the most economically important crops. It is important source of food, fuel and wood for people and coconut palms symbolizes exotic holidays and in deed tourism is a very important source of income for southern of Thailand (Sindhusake and Winotai, 2004). Thailand’s coconut industry consists almost exclusively of smallholders with just over 50,000 farmers involved; most of these farmers have an area of about 2.5 ha. of palms. Yields are low at around 6.6 MT/ha. and incomes are low as the price per kiologram is only about 8 THB (Thai bath). The total area under coconut is estimated at 328,000 ha. with produces about 1,146 million nuts or about 344,000 MT in copra equivalent, representing a total value of 902.16 million THB domestically and with exports of 512,330 million THB (34 THB = US$ 1). Coconut is not only an important local food crop, but is perhaps even more important for tourism industry (Liebregts and Champman, 2004). However, the beautiful coconut palm is now under threat from pest and disease. Besides reducing production or often killing coconut palms, insect pests could possibly affect tourism as such symbols that foreign tourists seek are destroyed.

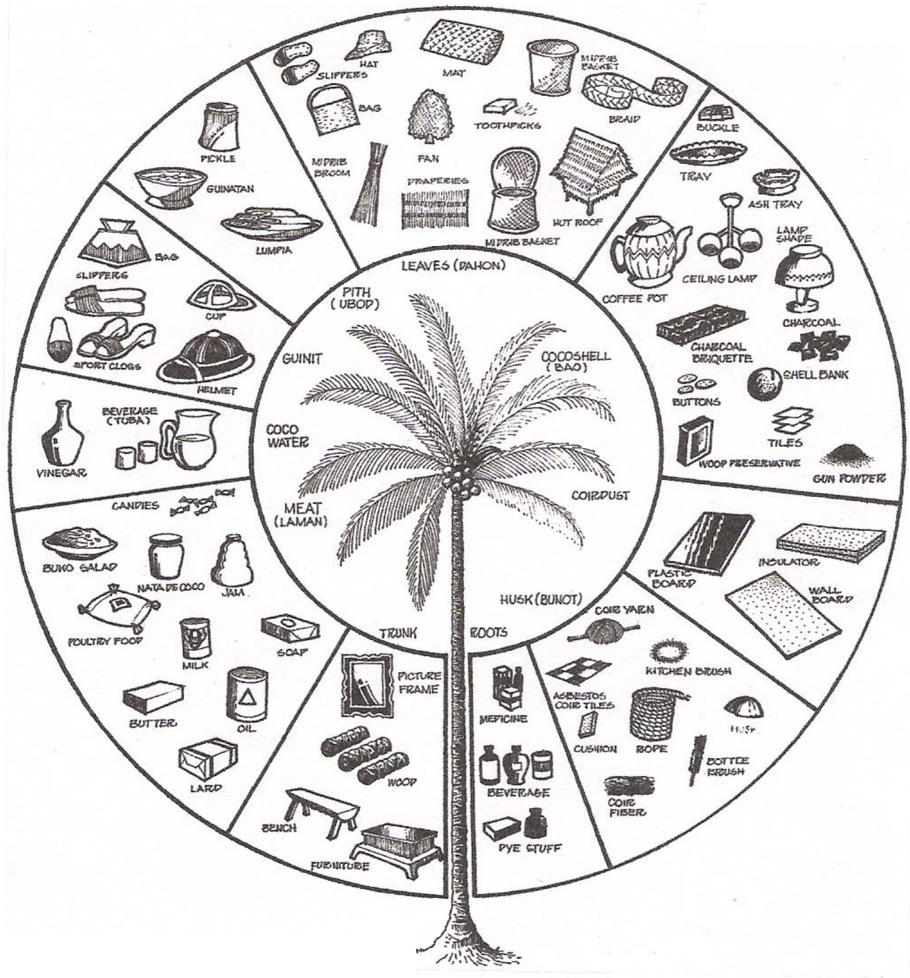


Figure 1 Utilization of by products of coconut palm.

Source: Philippines Council for Agricultural Research (1975).

2. Pests of coconut

Coconuts are attacked by many pests and diseases. Besides pathogens, there are several invertebrates (nematodes, arthropods *etc.*) and vertebrates (rats, birds, *etc.*) which attack various stages of the plant (Lever, 1969; Krantz *et al.,* 1978 and Red Ring Research Division, 1983). At least 751 insect pests of coconut have been recorded from around the world. These insect pests attack the leaves, stems, flowers, nuts and roots of the coconut plant. One of the 751, Coleoptera is the most numerous, totaling 323 species (Child, 1974). The pests of coconut palm have a ready supply of abundant food and they can multiply uninterrupted all the year round with the result that the coconut plantations are often seriously damaged (Menon and Pandalai, 1960). Insect pests may be classified into several groups, depending either on the part of the plant they attack or on whether they act directly or as the vector of a disease. The pests attack leaves by leaf-eating may destroy leaves partially or completely, decreasing photosynthesis and hence yields. Some pests biting or sucking may attack leaves, in which case they have the same effects as leaf-eating insects. Flowers and fruits attack causing premature drop of young nuts, with a consequent reduction in copra yields. Some sucking insects are disease vectors. Some also transmit diseases that diseases affect the leaves, flowers and fruits. These are usually fungal and are rarely fatal. Other diseases, in contrast, affect the whole tree and may result in its death. These are often transmitted by sucking insects or borers (Gabriel, 1998). The more important pests of coconut according to their natural order are described in Table 1.

Table 1 Orders and families to which the insect pests of the coconut palm belong.

Order	Family	Characteristics
Coleoptera	Chrysomelidae Curculionidae Lucanidae Lymexylonidae Melolonthidae Scarabaeidae Scolytidae	Forewings (elytra) tough, opaque, at rest usually covering the membranous hind wings. Larvae with three pairs of legs or without legs. Early stages entirely different from adults. (Beetles.)
Diptera	Ortalididae Scholastidae	Only one pair of wings. Early stages entirely different from adults. (The order Diptera contains a vast assemblage of flies with only two wings; some of them, notably in the family Tachinidae, are beneficial as enemies of coconut pests.)
Hymenoptera	Formicidae	The ants live in communities organized in castes, in general males, workers and queens. Certain species are beneficial predators. Early stages entirely different from adults. (The order Hymenoptera also contains the bees and wasps, including several families of parasitic wasps, many species of which are beneficial as enemies of coconut pests.)
Isoptera	Kalotermitidae Rhinotermitidae Termitidae	Social insects living in communities composed of well-marked castes, such as reproductives, workers, soldiers and queens; structure and arrangement of nests vary greatly according to family and species. (Termites or white ants.)
Lepidoptera	Agonoxenidae Amathusiidae Brassolidae Castniidae Cosmopterygidae Cossidae Cryptophasiidae Galeriidae Hesperiidae Limacodidae Noctuidae Phycitidae Psychidae Pyraustidae	Two pairs of wings, covered with scales, usually forming conspicuous pattern and/or color. Larvae mostly leaf-eaters and free-living, but some construct webs or bags and others tunnel in truck, nuts or spadices. Pupae in soil, or in cocoons, or suspended by silken girdle or freely. Early stages entirely different from adults. (Butterflies and moths.)

Table 1 (Continued)

Order	**Family**	**Characteristics**
Lepidoptera (continued)	Satyridae Zygaenidae	
Orthoptera	Acrididae Gryllidae Tettigoniidae	Hind legs saltatorial; forewings tough, at rest covering membranous hindwings. Eggs laid in the soil; early stages similar to adults in form and mode of life. (Grasshoppers, locusts, crickets.)
Phasmida	Phasmidae	Body very elongate, stick-like; wings small or absent. Eggs seed-like, laid freely in trees, often dropping to the ground. Early stages similar to adults. (Stick insects.)
Rhynchota Or Hemiptera	Aleurodidae Aphididae Coccidae Coreidae Pentatomidae Tingidae	This order is divided into: Heteroptera (including Coreidae, Pentatomidae and Tingidae) and Homoptera (including Aphididae, Coccidae and Aleurodidae); in the Heteroptera basal zone of forewings thickened, differing from distal zone, wings when at rest flat on back, crossed distally; in the Homoptera, forewings and hindwings, if present, similar and uniformly membranous. Early stages similar in form and mode of life to adults. (Plant bugs, including Homoptera aphids, scale insects, white flies.)

Source: Lever (1969).

Insect pests are major constraints to enhancing productivity. Coleopteran pests cause varying degrees of damage in different countries. This paper considers the coconut hispine beetle, red palm weevil and rhinoceros beetle that cause enormous damage to various cultivated coconut palm.

3. Coconut Hispine Beetle, *Brontispa longissima* Gestro

3.1 Biology and ecology of coconut hispine beetle and their control

The coconut hispine beetle, *Brontispa longissima* Gestro (Coleoptera: Chrysomelidae) is potentially one of the most serious pests of coconut palms (Liebregts, 2006).

3.1.1 Biology and ecology

The beetle developmental life cycle starts with the eggs phase followed by the larval phase. After going through several instars, the larva develops into a pupa from which the beetle emerges (Figure 2) (Liebregts, 2006). There are unusually four instars, with up to six instars in rear cases (Howard *et al*., 2001 *cited* Pagden and Lever, 1935; Froggatt and O'Connor, 1941).

- Egg The eggs are brown and flat. They are laid singly or in groups of two to four on the still-folded heart leaves. An egg measures 1.4 mm. in length and 0.5 mm. in width. Egg hatch in 3-4 days (Froggatt and O'Connor, 1941; Lever, 1969).

- Larva The newly hatched larvae are whitish, later turn to yellowish and have an average length of 2 mm. The older larvae have an average length of 8-10 mm. Larvae avoid light and have distally U-like hooks. The larvae have four larval instars or five to six larval instars. The total developmental period of larvae vary about 30-40 days (O'Connor, 1940; Froggatt and O'Connor, 1941).

- Pupa The newly formed pupae are yellowish-white and have an average length of 9-10 mm. and a width of 2 mm. They have distally U-shaped hooks. The pupal period is six days (O'Connor, 1940; Waterhouse and Norris, 1987).

- Adult The adult beetles are elongate, dorsoventrally flattened and 8-12 mm. long. The color of beetles from different localities varies greatly, from reddish brown to black, and some extreme color forms were formerly recognized as distinct species (Gressitt, 1957; Lever, 1969). The adult male is generally smaller than the female and measures 7.5-10 mm. in length and 1.5-2 mm. in width. They avoid light and stay inactive inside the still-folded heart leaf during day time and active fly and attack coconut plants at night. Pre-oviposition period is 74 days or one to two months. The adult beetles have been recorded as living up to eight months under ambient temperatures, and a single female can lay more than 430 eggs during her lifetime (O'Connor, 1940; Waterhouse and Norris, 1987; Liebregts *et al*., 2006).

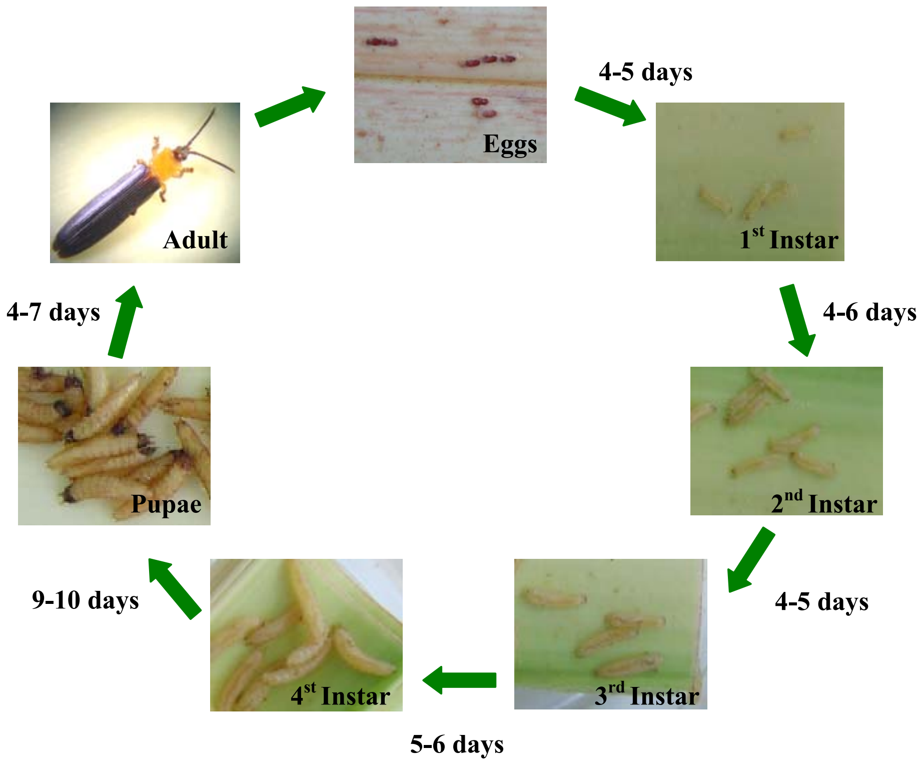


Figure 2 Life cycle of *Brontispa longissima* Gestro.

3.1.2 Distribution of coconut hispine beetle

Coconut hispine beetle is native to Indonesia (Aru Islands, Maluku Province and possibly Papua Province, formerly Irian Jaya) and also to Papua New Guinea, including the Bismarck Archipelago. It is now distributed in Asia, Australia and Pacific Islands attacking not only coconut palm but also several others palm species (Figure 3) (Rethinum and Singh, 2005). However, this invasive pest is new to continental Southeast Asia where, in the absence of natural enemies, it is rapidly spreading and causing massive damage. In Thailand It was first found in Narathiwat Province, the border area near Malaysia, in 2000. Heavy infestation was first reported in February 2004 in Southern provinces including Surat Thani (Samui Island and Pa-ngan Island) and Prachuap Khiri Khan (Sindhusake and Winotai, 2004).

Figure 3 Distribution of *Brontispa longissima* Gestro (black dot).

Source: Rethinum and Singh (2005).

3.1.3 Host Plants

It is commonly found on the coconut palm. Beside coconut palms, the coconut hispine beetle is capable of attacking other palms also. The most important of these are the petticoat palm, *Washingtonia robusta,* the sago palm, *Metroxylon sagu*, the royal palm, *Roystonea regia*, the betelnut palm *Areca catechu*, the pigmy date, *Phoenix roebelenii*, the oil plam, *Elaeis guineensis*, the nicobar palm, *Bentinckia nicobarica*, the carpentaria palm, *Carpentaria acuminate*, the fish tail palm, *Caryota mitis*, the ivory nut palm, *Phytelephas macrocapa*, the king palm, *Archotophoenix alexaandrae*, the hurricane palm, *Ptycosperma macarthurii*, the yellow butterfly, *Chrysalidocarpus lutescens*, the nipa palm, *Nypa fruitican*, the fox tail palm, *Wodyetia bifurcate* and sometimes it has been reported feeding on Cycadaceae (Rethinum and Singh, 2005).

3.1.4 Damage

The beetle attacks palms of all ages, especially damages young palm trees in nurseries and new leaves of palm trees, confining its damage to the tender unopened central leaves of palm trees where it seldom causes serious problems (Figure 4). Neglected palms are more heavily attacked. The beetle sometimes occurred together with other palm pests. In some cases fruit shedding took place with loss of yield (The National Nido Project, 1998). The beetle can cause significant production losses, and high infestation levels may result in tree death. With other palms productivity and appearance is severely affected by sublethal attack. The damage caused by the insect leads to leaf burn, yield loss and in many cases, plant death (Liebregts *et al*., 2006).

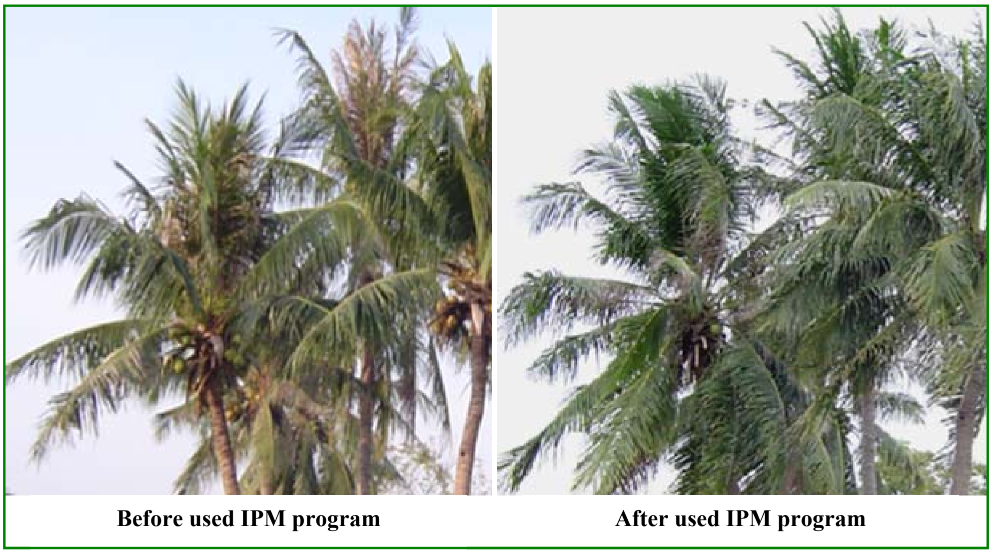


Figure 4 Coconut palm damaged by *Brontispa longissima* Gestro before and after used IPM program at Panya Indra golf course, 2007.

3.1.5 Economic loss and threat to livelihood

In the Maldives, economic losses caused by the coconut hispine beetle are significant. There, coconut is not only an important local food crop, but is perhaps even more important for tourism industry. Management from one Resort Island estimated losses between June 2000 and February 2003 at US$ 237,000 already due to a decline in tourism because of unhealthy palm trees and shift in labor from productive activities to insecticide application. Losses in revenue from coconut sales and drinks are estimated at a further US$ 33,000 for the same period for the holiday islands. Coconut hispine beetle represents a threat to the coconut industry of the southern and central parts of Thailand with US$30 million production and 50,000 smallholder farmers. It is reported that the total areas hit by the coconut beetle outbreaks amounted to 7,229 ha. (Luigi, 2005).

3.1.6 Control strategy for coconut hispine beetle

This strategy includes prevention as well as short term and long term sustainable control methods. A three-pronged approach will be follow:

- <u>Quarantine measures</u> When the coconut hispine beetle was first found, many quarantine measures were taken. The affected trees were cut down and burned, broad spectrum insecticides were screened and the insecticide bags were inserted at the base of the unopened leaf to establish a three kilometers buffer zone to prevent the spread. Transporting the palm trees from other provinces or from country to country was strictly forbidden. Check points were established to enforce this regulation. Epidemic survey was started immediately and the epidemic plots were established at which highly susceptible hosts were planted. Regular surveys were carried out. A mechanism of reporting epidemic was established for timely action; the telephone number of epidemic reporting service was publicized. A manual of controlling coconut hispine beetle was developed and distributed to the public so that once anyone found the infesting beetles at any spot that they could report immediately (Yueguan and Yankun, 2004). To avoid introduction of such pest into country, it is important to be cautious when importing planting materials, soil and organic materials. All planting materials should accompany a reliable State Phytosanitary Certificate from the exporting country. All organic materials should be thoroughly sterilized to destroy all eggs or immature insects (Hassan, 2003).

- <u>Chemical control</u> Initially insecticides were used to control the pest when the beetle was first found. Broad spectrum insecticides such as imidacloprid, cypermethrin, deltamethrin and matridine were applied by spraying with high pressure applicator or elevator at intervals of three to four weeks. Some insecticides were injected to the trunk of infest palm trees. The insecticide powder was put into the bags that were hung on the palm trees (Yueguan and Yankun, 2004). A more effective and less toxic chemical Diazinon 10% Granules trade name Diaphos was introduced. Diaphos 10 g per bags were inserts at the base of the sheath of unopened leaf. Diaphos packet of 30G per tree was enough for controlling the beetles efficiently for two to three months. To avoid re-infection, Diaphos was applied to all palms at the same time (Shafia, 2004). Use carbaryl at 1.25 g of 80% wettable powder; add an agricultural wetting agent at the recommended rate to the diluted spray to improve coverage and penetration. Spray on to leaves which have not completely opened, covering both leaf spaces and penetrating the spaces between leaflets. Do not apply during flowering as carbaryl is toxic to bees (The National Nido Project, 1998). In severe infestation, an insecticide, imidacloprid with 2 L of the dilution at 2 ml/L can be drenched around the root zone of each palm. Each application is good for 6 months (Pheng *et al*., 2004).

- Biological control The use of pesticides may also be applied, but this can be expensive, especially on large scale. Resorts or private individuals with the funds to apply this method in coconuts raise serious concerns about the health risks of the farmers, families and consumers. Coconuts generally sell for a low price, and pesticide application to trees for coconut hispine beetle control is particularly hazardous. The trees are tall; applicators must climb up to the crown, and workers ask a high price for this dangerous task. They typically work without protective clothing, and are exposed to pesticide through the skin and via inhalation as they struggle to keep their balance while spraying beetle larvae in folded young leaves. Moreover, coconut plantations are often situated near homes, resorts, golf courses so that detrimental effects on the health and environment of households, fishponds, gardens and domestic animals due to pesticide exposure must be seriously considered. Therefore, biological control is considered to be the best approach to solving this pest problem. According to scientific literature, this insect pest can be completely controlled at low cost by using natural enemies (Table 2) (FAO, 2004).

Table 2 Natural enemies of coconut hispine beetle, *Brontispa longissima* Gestro.

Species (Order: Family)	**Reported locations**	**Remarks and references**
Egg parasitoids		
Hispidophila (Haeckeliana) Brontispae Ferriere (Hymenoptera: Trichogrammatidae)	Java, Indonesia	Described in 1931, one wasp /egg; parasitized 15% eggs in the field (Kalshoven, 1981).
Ooencyrtus podontiae Gahan (Hymenoptera: Encyrtidae)	Java, Indonesia	Parasitized 10% eggs (Kalshoven, 1981). In 1941, eggs, parasitized by *Ooencyrtus* were introduced from Bogor. Introduced to several countries for evaluation, recorded in Malaysia.
Trichogrammatoidae Nana Zehntner (Hymenoptera: Trichogrammatidae)	Java, Indonesia	Described in 1896, a successful egg parasitoid and several other coconut pests. Native to Java (Indonesia); introduced to Fiji, Papua New Guinea and Solomon Islands.
Larval/pupal parasitoid		
Tetrastichus brontispae Ferriere (Hymenoptera: Eulophidae)	Java, Indonesia	Found in 60-90% of the pupae and 10% of the larvae (Kalshoven, 1981). Considered a most effective species, widely introduced in the Pacific Islands for control.
Asecodes hispinarum Bouček (Hymenoptera: Eulophidae)	Samoa	Larval parasitoid collected from Samoa and released in Nauru, Vietnam, Maldives and Thailand.
Chrysonotomyia sp. (Hymenoptera: Eulophidae)	Samoa	Parasitoid was the most important cause of larval mortality, parasitizing 75% of the fourth instar larvae collected from Samoa.
Entomopathogenic fungi		
Metarhizium anisopliae (Metchnikoff) Sorokin (Moniliales: Moniliaceae)	Samoa	Widely distributed soil-inhabiting entomopathogenic fungus. Isolated in several locations and successfully used for control in Samoa and Taiwan.
Beauveria bassiana (Balsamo) Vuillemin (Moniliales: Moniliaceae)	Samoa	Common fungus, spraying of coconut trees with 5×105 conidia/ml was effective against adults and larvae.

Table 2 (Continued)

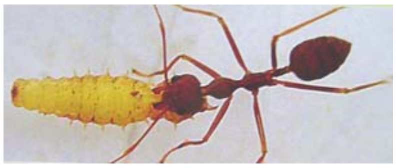
Species (Order: Family)	Reported locations	Remarks and references
Predator		
Chelisoches morio Fabricius (Dermeptera: Chelisochidae)	Java, Indonesia	Important predator of *Brontispa*, available in most of its distribution zones.

Source: Rethinum and Singh (2005).

Biological control will take some time to implement in the new area of spread. The biological control agent of coconut hispine beetle show in Figure 5. Among the natural enemies used in biological control, information about predators against chrysomelid beetles is still limited. Waterhose and Norris (1987) reported some earwigs preying on *B. longissima*. However, no research has been done to study the basic aspect of the predator and to develop them as an important potential biological agent (Meldy *et al*., 2004). The egg parasitoids are parasitized by *Trichogrammatoidae nana* (Zhnt.) and the larval parasitoid by the Eulophid *Tetrastichus brontispae* Ferrière. These parasitoids were imported to the Celebes and New Guinea with successful results, but less successfully into the Solomon Islands (Child, 1974). *Asecodes hispinarum* Bouček (Hymenoptera: Eulophidae) is one of the most successful species to control. It is the larval parasitoid which is believed to originate from the Solomon Islands/Papua New Guinea region. This natural enemy was successfully introduced into Samoa in the early 1980s. Complete control has been achieved in several countries by importing and establishing parasitoids that attack immature stages of the pest.

Predators

Chelisoches morio



Oecophylla smaragdina

Parasitoids

Hispidophila brontispae

Trichogramma nana

Asecodes hispinarum

Tetrastichus brontispae

Entomopathogenic fungi

Metarhizium anisopliae

Figure 5 Biological control agents of coconut hispine beetle, *Brontispa longissima* Gestro.

Source: Rethinum and Singh (2005).

4. Red Palm Weevil, *Rhynchophorus ferrugineus* Oliver

4.1 Biology and ecology of red palm weevil and their control

The red palm weevil is a member of Coleoptera: Curculionidae. It is the most dangerous pest of the coconut palm and is found distribute in all the major coconut growing countries (Child, 1974). The male and female adults are large reddish brown beetles. Damage to palms is produced mainly by the larvae (Gomez and Ferry, 1999).

4.1.1 Biology and ecology

All stages are spent inside the palm itself and the life cycle cannot be completed elsewhere (Figure 6).

- <u>Egg</u> The female weevil lays its eggs in wounds along the trunk or in petioles, and also in wounds caused by the rhinoceros beetle. The eggs are creamy white in color, long and oval in shape and slightly broader at one end. They are translucent, perfectly smooth and shining. The average size of an egg is 2.6 mm. in length and 1.1 mm. in width. The eggs hatch in 3-4 days and increase size before hatching and the brown mouthparts at the narrow end of the egg can be distinctly seen through the shell (Menon and Pandalai, 1960; Alhudaib, 1998).

- <u>Larva</u> On hatching, the apodal larvae begin feeding towards the interior of the palm. In palms up to 5 years old the larvae may be found in the bole, stem or crown. As palms advance in age, the grubs are generally confined to the portions of the stem close to the growing point. In palms more than 15 years old, the larvae are generally found in the stem about 2-3 feet below the crown, in the crown bases of leaf petioles. The larval period ranges from 36-78 days (Howard *et al.*, 2001). The full grown larva is conical in shape and is a legless fleshy grub. It appears yellowish brown, while the newly hatched larva is yellowish white in color, with a brown head. The length of the full grown larva is 50 mm. and the width is

20 mm. The head is brown in color and bent downwards. Mouth parts are well developed and strongly chitinized, which enable the grub to burrow into the trunk. However, the grub requires a moist environment. The body is composed of thirteen segments. The prothorax is very large and bears two transverse oblong patches, which are darker in color than the rest of the body (Menon and Pandalai, 1960; Alhudaib, 1998).

- Cocoon When about to pupate, the larva constructs a cocoon of fiber. The inside fibers are more closely matted together than those outside, which are arranged spirally. The interior of the cocoon is smooth and is plastered with a dark colored secretion. The cocoon is oval in shape varying in length from 50 mm. to 95 mm. and in width from 25 mm. to 40 mm. (Menon and Pandalai, 1960).

- Pupa The pupae are at first cream colored but later turn brown. The head is bent ventrally, the rostrum reaching the tibiae of the first pair of legs. The antennae and eyes are quite prominent. The elytra and wings are brought down ventrally, passing underneath the femora and tibia of the second pair of legs, overlapping the third pair of legs and meeting in the middle of the abdomen. The average pupa is 35 mm. in length and 15 mm. in width. The pupation period lasts 14 to 21 days, a life cycle of about four months (Alhudaib, 1998).

- Adult The adult weevil is a reddish brown cylinder with a long prominent curved snout. It varies considerably in size and is about 35 mm. in length and 12 mm. in width. The head and rostrum comprise about one third of the total length. The mouth parts are elongated in the form of a slender snout or rostrum, which bears a small pair of biting jaws at the end and a pair of antennae near the base. The rostrum is reddish brown dorsally, and ventrally it is dark brown. In the male the dorsal apical half of the snout is covered with a pad of short brownish hairs; the snout of the female is bare, more slender, curved and a little longer. The antennae consist of the scape and funicle. The eyes are black and separated on both sides of the base of the rostrum. The pronotum is reddish brown in color and has a few black spots. These black spots are variable in shape, size and number. The elytra are dark red, strongly ribbed longitudinally, and do not cover the abdomen completely. The wings are brown in color and the weevils are capable of strong flight. Red palm weevil is active during day and night, although flight and crawling of weevil is generally restricted to the day time. The weevil lays an average 204 eggs. The longevity of the weevil ranges from 2-3 months. In capacity, the maximum life span of the adult was 76 days for the female and 113 days for the male (Menon and Pandalai, 1960**;** Alhudaib, 1998).

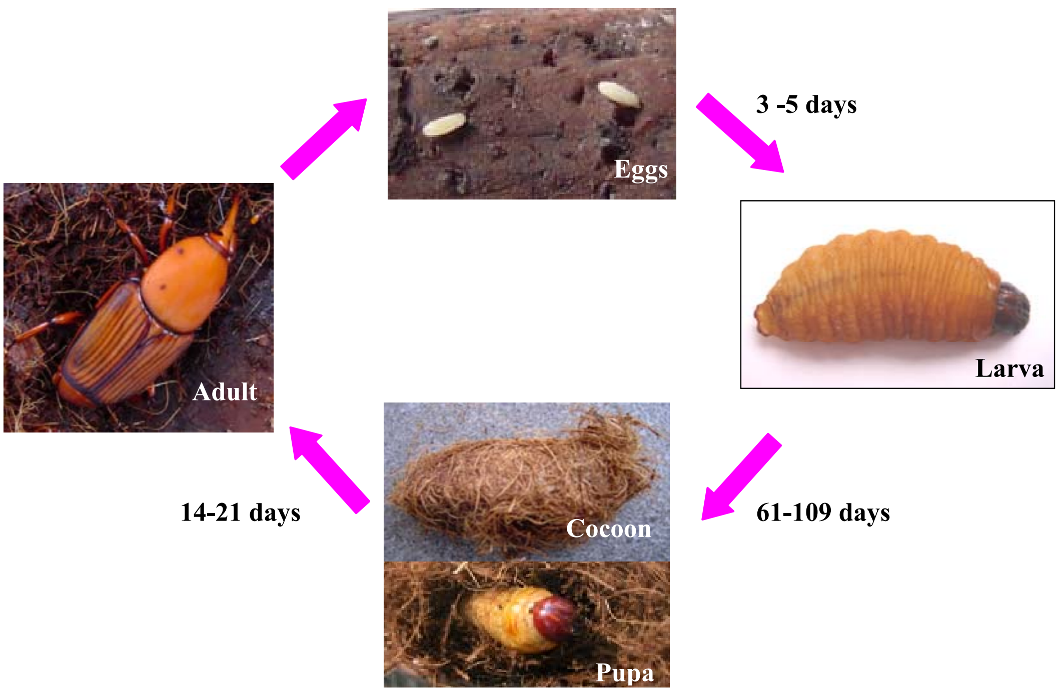


Figure 6 Life cycle of red palm weevil, *Rhynchophorus ferrugineus* Oliver.

4.1.2 Distribution of red palm weevil

The red palm weevil is an economically important tissue boring pest in many part of the world (Figure 7). Information on Red Palm Weevil was first published in India 1891. This pest was first described as a serious pest of the coconut palm in 1906, while in 1917 it was described as a serious pest in the date palm in the Punjab, India. Red Palm Weevil entered and was discovered during the mid 1980s in the Arabian Gulf countries. However, it has become a most destructive pest of date palms in the Middle East. Originating in Southern Asia and Melanesia where a serious pest of coconut is, this weevil has been advancing westwards very rapidly since the mid 1980s. The spread of the red palm weevil is from Spain over North Africa, Arabian Peninsula, Iraq, Iran, Pakistan up to Malaysia, Indonesia. It can be fixed that all over the palm vegetation belt around the earth relations of *R. ferrugineus* are present. The cause of high rate of spread of this pest is human intervention, by transporting infested young or adult date palm trees and offshoots from contaminated to uninfected areas (Alhudaib, 1998; Gomez and Ferry, 1999).

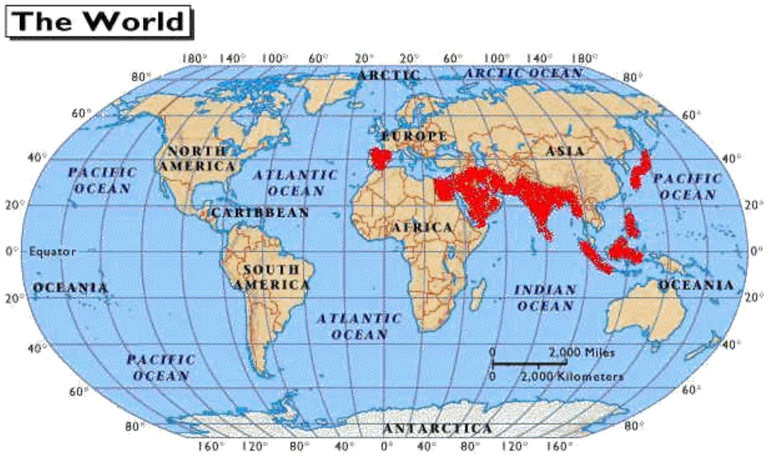


Figure 7 Distribution map of *Rhynchophorus ferrugineus* Oliver (red color).

Source: Alhudaib (1998).

4.1.3 Host Plants

It is commonly found on the date palm, *Phoenix dactylifera*, the coconut palm, *Cocos nucifera*, the sago palm, *Metroxylon sagu*, and the toddy palm, *Phoenix sylvestris*, the palmy palm *Borassus flabellifer*, the oil palm, *Elaeis guineensis*, the talipot palm, *Corypha umbraculifera*, the sugar palm, *Arenga saccharifera*, the serdang palm *Livistona chinensis,* the nibong palm, *Oncosperma tigillaria*, the royal palm, *Oreodoxa regia* and some ornamental palms also have been reported to be attacked by the weevil (Menon and Pandalai, 1960)

4.1.4 Damage

It is very difficult to detect the presence of the pest infestation in the earlier stages of attack. The grub begins its life inside the palm, and normally never comes outside. Therefore neither the grub nor the damage caused by it can be readily seen. Sometimes, a few small holes occur in the crown or the soft stem. In many cases the drying up of the young heart leaves or splitting of the petioles near the area of attack can be observed (Figure 8). But most often the attack by the weevil is noticed only when the trees has been fatally infested and is beyond repair (Menon and Pandalai, 1960). The damage caused by the pest is very severe and once the weevil gets access to the palm, the final death of the tree is more or less certain. The first indication is the presence of holes on the stem with chewed fibrous material, sometimes protruding out (Child, 1974). The red palm weevil is a concealed tissue borer and all of its life stages are found inside the palm tree. Damage symptoms are indicated by the presence of tunnels in the trunk, oozing of thick yellow to brown fluid from the tree, the appearance of chewed up plant tissue in and around opening in the trunk, the presence of a fermented odor from the trunk or topping of the crown (Kaaheh *et al*., 2001).

Figure 8 Coconut palm damaged by *Rhynchophorus ferrugineus* Oliver at Panya Indra golf course, 2007.

4.1.5 Economic impact

Menon and Pandalai (1960) suggested that *R. ferrugineus* is a serious pest of coconut palms in India and Sri Lanka. It damage in 34% of coconut groves in Cochin, India.

4.1.6 Control strategy for red palm weevil

The controlling possibilities are very limited due to the hidden lifecycle of the weevil. Young palms are especially liable to red palm weevil attack. Control measures against the rhinoceros beetle will help to minimize weevil damage. In addition care must be taken to avoid wounding young palms. When lesion does occur they should be tarred at once (Thampan, 1975).

- <u>Mechanical control</u> Dead palms or palms beyond recovery are to be split open, exposing the different stages of the pest present inside and the debris, including the out logs and crowns, are to be burned (Alhudaib, 1998).

- <u>Cultural control</u> Field sanitation and cultural practices are one of the important components to prevent weevil infestation (Alhudaib, 1998).

1. Clean the crown of palms periodically to prevent decaying of organic debris in leaf axils.
2. Avoid cuts and injuries.
3. When green leaves are cut, cut them at 120 cm away from the base.
4. Cutting of steps in palms for easy climbing is to be avoided, as this provides sites for egg laying by weevils.
5. As palms affected by leaf rot and bud rot diseases are more prone to weevil infestation, they are to be treated with suitable fungicides; after that, application of any insecticide to prevent egg laying by weevils is essential.
6. Destroy all dead palms harboring the pest by cutting and burning.

- Plant quarantine The transport of offshoots as planting material from infested areas can contribute to the spread of the pest. Strict quarantine at international and national levels should be applied (Alhudaib, 1998).

- Pheromone control The age and fecundity of female red palm weevils captured in food-baited pheromone (4-methyl-5-nonanol) traps placed in coconut plantations of Goa in Western India was assessed in the laboratory. Captured weevils were young and gravid. About 85% of pheromone trap captured female weevils confined to a celibate life in the laboratory were fertile and laid viable eggs indicating that they had already mated before entering the traps. The opportunity to mate enhanced oviposition and egg viability, while reducing the post ovipositional period of pheromone trap captured female weevil. The findings signify the potential benefit of using food-biated pheromone traps to curtail the population build up of red palm weevil in the field (Faleiro *et al*., 2003).

- Chemical control The chemical will spread the entire area and ultimately kill all grubs feeding inside the stem. Application of the systematic insecticide monocrotophos to coconut palm in South India in an early stage of infestation, but this method may involve the usual disadvantage of chemical control. Infestations of red palm weevil in palms are difficult to accurately detect prior to serious damage is obvious, the palm may die (Howard *et al*., 2001).

- Biological control Problems associated with chemical insecticides led to the necessity for the development of alternative control measures.

- Parasitoid The calliphorid *Sarcophaga fuscicauda* is a minor parasitoid of the weevil (Howard *et al*., 2001). The weevil is parasitized in Malaysia and Indonesia by *Scolia erratica* Smith, but in India is apparently not parasitized by any species of Scoliid wasp (Thampan, 1975). In Copeland in the Philippines, Leefmans in Indonesia and Huston in Ceylon have not found any Scoliid parasitizing this pest (Menon and Pandalai, 1960). Nirula *et al*. (1955) recorded a species of mites belonging to the family Pyemotidae as an external parasitoid on the pupae and adults of the weevil.

- Predator The ear wig predator has been found to be useful in the biological control of the pest. It is active from the fourth instar of the nymph. The maximum consumption of eggs and early instar of grubs are noticed in the adult stage of the predator (Child, 1974). There were some attempts in the laboratory and field using the *Chelisoches morio* in India (Kurian *et al*., 1983).

- Entomopathogenic control Nematodes of the families Steinernematidae and Heterorhabditidae could be valuable as biological control agents (Gaugler and Kaya, 1990). *Xenorhabdus* and *Photorhabdus* are bacterial symbionts within nematode intestine; after invading the host, they release these bacteria in the heamocoel of the host, where it proliferates, kills the host and establishes suitable conditions for nematode reproduction (Abdel *et al*., 2004 *cited* Smigielski *et al*., 1994). In the laboratory, most nematodes were pathogenic to the pest larvae, pupae and adults. Larvae and adults were more susceptible to nematode infection than pupae enclosed in their cocoons. In the field however, the highest insect larval mortality was 66.67% and most of nematodes failed in controlling the pest. Such failure could be due to hot weather, the tunneling behavior of the pest larvae and the too much sap in the infested sited in the trunks of palm trees (Abbas *et al*., 2001).

5. Rhinoceros Beetles, *Oryctes rhinoceros* L.

5.1 Biology and ecology of rhinoceros beetle and their control

The rhinoceros beetle, *Oryctes rhinoceros* L. (Coleoptera: Dynastidae), is one of the most damaging insects to coconut palm and African oil palm in the Southern and South East Asia and the Western Pacific islands. The adult rhinoceros beetles feed on the growing point of the palm producing eventually ragged appearance of mature palm leaves. A severely attacked palm will die or damage by secondary attack pests (Thampan, 1975).

5.1.1 Biology and ecology

The eggs of this pest are laid in rotting vegetation, especially in the trunks of rotting palms. The larvae bore and damage in the tunnel which constructed by feces and silk among the spikes of flowers. The life cycle lasts from 4 to 9 months allowing more than one generation per year (Figure 9) (Chen, 1988).

- Egg The eggs are yellowish-white, measuring 3 mm. in diam. and lay inside rotting vegetative matter. Initially oval in shape, they begin to swell about a week after lay and hatch within 11-13 days (Wood, 1968).

- Larva The larval stages are usually yellowish-white in color and may grow to about 60-100 mm. in length (Wood, 1968). The maximum head capsule width is about 10.6-11.4 mm. The cranium is medium to dark brown with numerous round pits many of which bear minute setae. The larvae are stout, sluggish and white in color with a pale brown head and are usually found in manure pits at a depth of 5-30 cm. Developmental period is 1st instar larvae 10 to 21 days, 2nd instar larvae 12 to 21 days, 3rd larvae 60 to 165 days, mature larvae are C-shaped, with brown head capsule and legs (Bedford, 1980; Howard *et al*., 2001 *cited* Gressitt 1953).

- Prepupa and Pupa The prepupa is similar in appearance to the larval stage, except that it is smaller than the final larval instar. Shriveled in appearance, it shakes its body activity when disturbed. The pupa is yellowish-brown in color and measure up to 50 mm. in length. It is segmented on the dorsal surface. The length of the horn shaped protuberance on the anterior may indicate the sex of the adult. The developmental period is prepupae 8 to 13 days and pupae 17 to 28 days (Wood, 1968; Lever, 1969).

- Adult The imagos remain in the cocoon for about 11 to 20 days. Imagos are large 35-50 mm. in length and 20-23 mm. in width, with a prominent horn on head. The males having a relative longer horn than the female. The adult is black or reddish black and stout. The male can be differentiated more accurately by having a rounded shiny terminal abdominal segment while the female has a relatively hairier 'tail'. Mating occurs in breeding sites. The adult longevity is about 4.7 months and fecundity per female is 108 eggs (Wood, 1968; Nirula *et al.*, 1955).

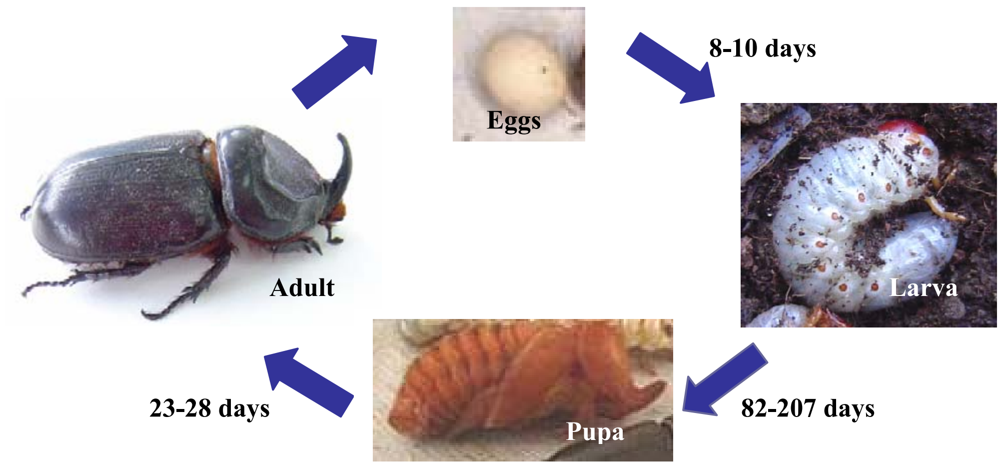


Figure 9 Life cycle of *Oryctes rhinoceros* L.

5.1.2 Distribution of rhinoceros beetle

The rhinoceros beetle is distributed throughout Asia and Western pacific (Figure 10). Thought to be native to the Southern Asiatic region, the rhinoceros beetle was introduced throughout the Pacific primarily as a result of the increased sea traffic during World War II. The beetle breeds in dead standing coconut palms were killed by pest, disease, lightning, decaying organic materials like compost and sawdust heaps. Floating logs containing larvae in tunnels might spread the pest to new areas (Bedford, 1980; Howard *et al.,* 2001 *cited* Gressitt, 1953).

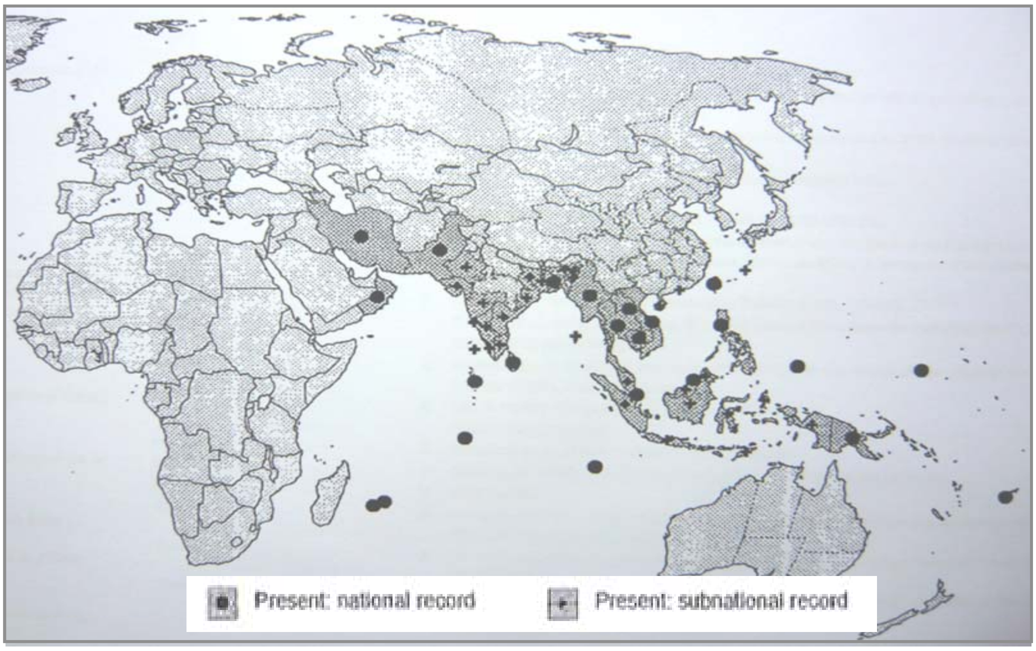


Figure 10 Distribution map of *Oryctes rhinoceros* L.

Source: CAB International (1998).

5.1.3 Invasion pathways to new locations

Aircraft: Rhinoceros beetle has been found alive in an aircraft hold and also in a polystyrene box containing tissue culture flasks from South East Asia.

Military: Introduced throughout the Pacific primarily as a result of the increased sea traffic during World War II.

Nursery trade: It is believed to have been introduced in rubber seedling pot plants from Sri Lanka to the Pacific island of Upolu, Western Samoa in 1909.

Transportation of habitat material: The beetle breeds in decaying organic materials like compost and sawdust heaps. Transportation of this material could be a pathway of introduction to new areas (Wood, 1968; Nirula *et al*., 1955; Nishida and Evenhuis, 2000).

5.1.4 Host plants

Besides coconut palms, the rhinoceros beetle is capable of attacking other palms also. The most important of these are the palmyra palm, *Borassus flabellifer*, the toddy or wild date palm, *Phoenix sylvestris* and the African oil palm, *Elaeis guineensis*. The other host plants are the date palm, *Phoenix dactylifera*, the areca palm, *Areca catechu*, the sago palm, *Metroxylon sagu*, the nipa palm, *Nipa fruticans*, the sugar palm, *Arenga pinnata*, the fan palm, *Livistona chinensis*, the serdang palm, *Corypha elata*, the talipot palm, *Corypha umbraculifera* and some other ornamental palms. Sometimes it has been reported feeding on agave, sugarcane, pineapple, tree fern, banana and taro; but these appear to be only accidental hosts (Menon and Pandalai, 1960).

5.1.5 Damage

The adult beetle bores into the soft tissue of the bud by cutting and chewing the tender unopened leaves and inflorescences. In the process, the leaves and inflorescences are severely damaged. The affected leaves, on emergence, will give a characteristic fan-like appearance where the leaflets are cut off in the same place on both sides of the leaf stalk (Figure 11). When the attack is on the unopened spathe, the inflorescence gets destroyed. Sometimes the beetles have also been found boring into the soft tissues of the tender nuts. Though death is not common in the grown up trees, the beetle may cause death of the young palms by boring into the growing point and destroying it (Thampan, 1975). In oil palm the rhinoceros beetle bores into the base of cluster of spears, causing wedge shaped cuts in the unfolded fronds. In younger palms the effect of damage can be much more severe (Wood, 1968). Attack by adults may reduce yield and kill seedlings. They may provide entry points for lethal secondary attacks by the red palm weevil or pathogens (Bedford, 1980).

Figure 11 Coconut palm damaged by *Oryctes rhinoceros* L. at Panya Indra golf course, 2007.

5.1.6 Economic loss and threat to livelihood

The beetle bores into the cluster of spears, causing wedge shaped cuts in the unfolded fronds or spears. In young palms where the spears are narrower and penetration occur lower down; the effects of damage can be much more severe than in older palms (Wood, 1968). The young palms affected by the beetle damage are believed to have a delayed immaturity period. Although Wood (1968) suggested that the damage to the immature palms results in relatively small crop losses, field experiments revealed an average of 25% yield loss over the first two years of production. In India damage of inflorescence is also reported in severely infested areas which cause reduction in yield up to 10% (Nair, 1986). The beetle caused a loss in yield of 5.5 to 9.1%. From artificially pruned leaf damage stimulation studies it was observed that damage to 50% fronds corresponds to leaf area reduction of 13% and decrease in nut yield by 23% (Young, 1974).

5.1.7 Field Monitoring/Economic Threshold Levels

On the palm, the economic threshold for rhinoceros beetle still needs to be investigated and developed. The leaves of coconut were used to investigate. The crown of the coconut palm has about 30 to 40 paripinnate leaves, 3-6 m. long (frond) (Janick and Paull, 2008). An adult leaf consists of a strong petiole which extends into a rachis bearing 200-300 leaflets (Figure 12). They are firmly attached to the rachis, froming a V-shape (Taffin, 1998). The leaf originates from the bud, where it is folded up in many plies, firmly pressed together. A new leaf first appears as a solid, compact spear-like structure which slowly gets unfolded and opens out by the action of a spcial swelling tissue. The life span of a leaf, from its emergence to shedding, is about 2.5-3 years and a new leaf appears in the crown every three or four weeks in a healthy palm (Thampan, 1975).

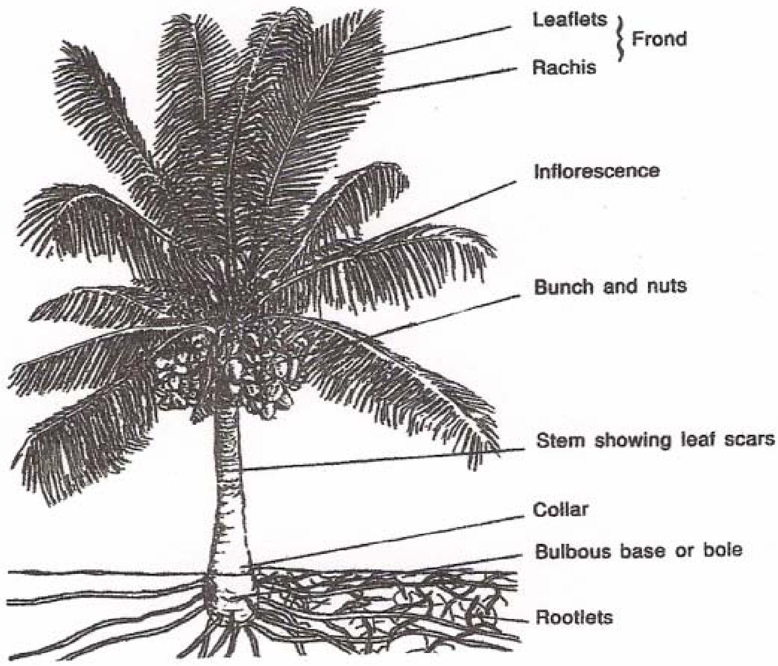


Figure 12 Vegetative structure of the coconut palm.

Source: Taffin (1998).

Wood (1968) developed four categories of damage to young palms which may be to used determine the severity of infestation in a particular area.

Category 1: Slight damage - limited signs of damage to fronds with little or no damage to spears.

Category 2: Medium damage - numerous damaged fronds but with new healthy spears.

Category 3: Severe damage - many fronds damaged and only short, distorted spears emerging. Spear rot does not affect all spears.

Category 4: Dead palms - fronds severely damaged, all spears rotting and can be lifted out easily with no live spears to emerge. Some palm of this category may recover.

These categories may change between the observation periods, thus indicating the beetles' activity. If a census of one row in every 10 is conducted and more than 10% incidence of damage is found, this indicates high beetle activity and control measures should be conducted immediately. The number of beetles found affecting young palms per hectare can also be considered as threshold levels for initiating control measures. The detection of 3-5 adult beetles per hectare for the first two years of the crop initiates control measures. However, the level can be increased to 15-20 adults per ha. once the palms have grown for more than two years (Wood, 1968).

5.1.8 Control strategy for rhinoceros beetle

- <u>Cultural control or Sanitation</u> Within surrounding the plantations, especially destruction of the potential or existing breeding sites of this pest, provides an important basis for its control. Manure heaps and pits may have to be covered or alternatively turned regularly for removal of the larvae. The establishment of a good larvae will fast growing ground cover provides a vegetative barrier (Figure 13) that hampers the movement of the adult beetle looking for suitable breeding sites. This restricts the damage in palm to low levels (Wood, 1968). Removal of the adults from the point of attack in young palms by using a hooked piece of iron (Figure 14) can be considered a common mechanical control technique to reduce the number of adults in an infested area. This practice is often costly, labor intensive and needs to be conducted regularly, provide that sufficient labor is available. However, some additional damage may be inflicted to the young palms during the search for adults, making the practice not entirely satisfactory (Howard *et al*., 2001 *cited* Ho and Toh, 1982).

Figure 13 Breeding sites of *Oryctes rhinoceros* L. for adult beetle looking for breeding in vegetative barrier.

Source: Bourgoing (1991).

Figure 14 Control adult *Oryctes rhinoceros* L. beetle by piercing with an iron hook.

Source: Bourgoing (1991).

- Physical control A method for trapping adults, consisting of a piece of holed coconut trunk with a tin can placed right below it leaving no space between them. The whole trap is set at height of 1.8 m. from the ground. There was no chemical attractant used in this trap: the decaying trunk served as the attractant. This trap used ethyl dihydro-chrysanthemumate as synthetic chemical attractant (Bedford, 1980). The trap used to monitor population trends at a density of 23 traps per eight hectares. To control beetle infestation, the density of the traps should be increased at the borders of a known source of infestation than inside the field (Young, 1974). The use of light traps for controlling populations has been found to be ineffective: Wood (1968) indicated that beetles do not often enter traps although they are attracted to the light source. However, light traps may be useful for monitoring.

- Pheromone control A synthetic aggregating pheromone, ethyl 4-methyloctanoate, has been developed for rhinoceros beetle. The pheromone was reported to be 10 times more effective in attracting beetles than ethyl-chrysanthemumate. The pheromone is stored in a small, heat-sealed, polymer membrane bag and placed on top of interlocking iron vanes mounted on a plastic bucket (Figure 15). The beetles attracted by the pheromone are trapped inside the bucket. Thus far, the pheromone shows some promise as a monitoring tool and as an economical control method, when placed at a density of one trap for every two hectares (Wood, 1968).

Membrane lure

Pheromone bucket

Figure 15 Pheromone lure and pheromone bucket trap of *Oryctes rhinoceros* L.

Source: Loring (2007).

- Chemical control Most of the chemicals applied are targeted to control the adult stages attacking the spear of the palm. The point of application is therefore at the leaf sheath. This method involves periodical examination of the palm crown and extracting the adult beetle by means of a metal rod about 0.5 m. long with a hook at one end during peak periods of pest abundance (June to September) from the infested site. The bore hole has to be filled with a mixture of 3 g Mancozeb + 1 kg sand. Application of 25 g Sevidol 8G (Lindane + Carbaryl) mixed with 200 g fine sand into the well around the base of the spindle repels the beetles (Nair *et al*., 1997). Granular formulations of the insecticides gamma-BHC and carbofuran were most effective as it facilitates applying them in the frond axils and thereby lowering costs compared to spraying liquid formulation. Treatment with 10% granules of Phorate is reported to give protection for up to 60 days when applied at 5 g per tree (Jayaraman, 1985). Insect repellent naphthalene applied fortnightly to the frond axils provided 95% control of the pest. Application of naphthalene balls in the leaf axil at the base of spindle leaf 12 g per palm is reported to provide good protection against the pest in Malaysia and India. This treatment gives 45-60 days protection to the palm (Singh, 1987; Sadakathulla and Ramachandran, 1990). Application of oil cakes of neem

(*Azadirachta indica* A.Juss., Meliaceae) or marotti (*Hydnocarpus wightiana* Bl., Bixaceae) in powder form 250 g mixed with equal volume of sand , three times per year to the base of the spindle leaf of coconut palm is an effective prophylactic method against rhinoceros beetle (Chandrika *et al*., 2001). Juvenile hormone mimics have been tested on pupae and indicated that methoprene was effective in causing death of the developing adult at the pupal stage. The use of long residual insecticides for drenching the breeding sites has been found effective to suppress the larval stages up to 7 months. The insecticidal treatment at the bottom soil of manure pits may also be useful to suppress the larval stages (Howard *et al*., 2001 *cited* Ho and Toh, 1982).

- <u>Biological control</u> Biological control of the beetle is the most important component of the IPM package. A variety of biological control agents have been attempt for the control pests of coconut palms.

- <u>Parasitoid</u> Insect parasitoid most attention has been directed to *Scolia*. The larvae of which wasps feed as external parasites on the rhinoceros beetle grubs. For examples, introductions are *S. oryctophaga* Coq., which parasites in Madagascar, to Mauritius; *S. ruficornis* F. from Zanzibar to Samoa; both of these into pupae. Results have been very variable (Thampan, 1975). The Scoliid parasitoid is successful introduction into Western Samoa in 1967 (Waterhouse and Norris, 1987).

- <u>Predator</u> Insect predators are frequently observed in the natural breeding grounds of the beetle, which feed on the eggs and early instar larvae of the beetle. The important predators are *Santalus parallelus* Payk., *Pheropsophus occipitalis* Macleay, *P.lissoderus*, *Chelisoches morio* (Fab.) and species of Scarites, Harpalus and Agrypnus. As these predators help in the natural check of the pest population, conservation of the predator fauna is essential. As these predators help in the natural check of the pest population, conservation of the predator fauna is essential (Antony and Kurian ,1966; Kurian *et al.,* 1983).

- <u>Entomopathogenic fungi</u> The green Muscardine fungus *Metarhizium anisopliae* is a pathogen which kills the pest in conditions of low temperature and high humidity. The susceptibility of *O. rhinoceros* to the fungus was first reported in Western Samoa in 1913 and in India. *M. anisopliae* var. *major* (spore size 10-14 µm) is a highly infective variety widely used for the control of this pest. The fungus could be mass multiplied using cheaper substrates both solid and liquid media and the spores could be harvested and treated in the breeding sites (Mohan and Pillai, 1982; Dangar *et al.,* 1991).

- <u>Viral pathogen</u> The viral pathogen Baculovirus of *Oryctes* (OBV) is very effective and kills the grubs in 15-20 days of infestation and it affects the longevity and fecundity of adult beetles. As the virus multiply in the midgut epithelium, the fat body disintegrates and the haemolymph content increases giving the larvae a transluscent appearance. Extroversion of the rectum may also occur. Presence of this virus in the host can be detected by 3% Giemsa staining of midgut fluid or midgut epithelium where in the pink colored hypertrophied nuclei with dark pink. Peripheral ring is observed in the infected sample under microscope (Mohan *et al.,* 1983).

6. Larval parasitoid, *Asecodes hispinarum* Bouček

6.1 Biology and ecology of *Asecodes hispinarum* Bouček and their role in biological control

Asecodes hispinarum Bouček (Hymenoptera: Eulophidae) is an effective parasitoid of *B. longissima* (Figure 16). It is a larval parasitoid which is believed to originate from the Solomon Islands/Papua New Guinea region. This natural enemy was successfully in Samoa in the early 1980s to control the coconut hispine beeltle, *B. longissima* incursion (Liebregts *et al*., 2006). Complete control of *B. longissima* has been achieved in several countries by introducing and establishing *A. hispinarum*. This parasitoid was collected in Samoa in 2003 and introduced, reared and released in Vietnam, the Maldives and Nauru to combat the beetle. The parasitoid is established in all three countries, with promising prospects for achieving control of the beetle (Rethinam and Singh, 2005). In order to control coconut hispine beetle in Thailand, *A. hispinarum* was introduced in August of 2004. The first release of the parasite was made at Koh Samui and Surat Thani on October 9, 2004 (Winotai *et al*., 2007).

Figure 16 Male and female adult of *Asecodes hispinarum* Bouček, a larval parasitoid of *Brontispa longissima* Gestro.

6.1.1 Biology and ecology

A. hispinarum is a tiny wasp, about 0.6-0.7 mm. in length, with flagella antenna segments of more or less gradually tapering towards the apex of the antenna. The scutellum lacks a pair of sibmedian lines/grooves, and the marginal fringe of the forewing is longer than the stigmal vein, especially at the anal angle (posterior part of the apical margin). The forewing has two setae on submarginal vein dorsally (FAO, 2003). Mating of *A. hispinarum* takes place shortly after female emerge from the mummified larvae of *B. longissima* (mummies). The female of *A. hispinarum* of seek out suitable hosts mostly 3rd and 4th instars of *Brontispa*, to lay their eggs (Figure 17). A female of *A. hispinarum* can lay more than 100 eggs into one larva of *B. longissima*. The larvae of *B. longissima* that have been parasitized will gradually change to a dark brown color. The parasitized larvae will turn into mummies after 10 days (Figure 18). The development of the parasitoid from egg to adult takes about 17 to 20 days, depending on the temperature and the other factors in their environment (Liebregts *et al*., 2006). The developmental stages of *A. hispinarum* under the laboratory condition of 24±2°C and 75±10% RH, the mean developmental duration of egg, larva and pupa were 2.5 days, 6.7 days and 7.5 day, respectively (Figure 19). The longevity of adult parasitoids without nutritional supplement is 2.3 days on average (Yueguan, 2007). Prior to emergence, the pupal cuticle was shed and adult coloration could be seen through the mummy, adult emergence occurred through holes chewed in the dorsum or abdomen cuticle of mummy by the adult parasitoid. Adult parasitoid emergence holes were made in 20-30 min., with most making 3-5 exit holes per mummy (Figure 20) (Lu *et al*., 2008). The parasitoids can be used immediately after emergence for parasitization of *Brontispa* larvae (Liebregts *et al*., 2006).

Figure 17 Parasitoid of *Asecodes hispinarum* Bouček parasitizing on *Brontispa longissima* Gestro larva.

After 3 days 5 days 7 days 10 days 14 days

Figure 18 Symptoms of parasitization by *Asecodes hispinarum* Bouček on *Brontispa longissima* Gestro larva.

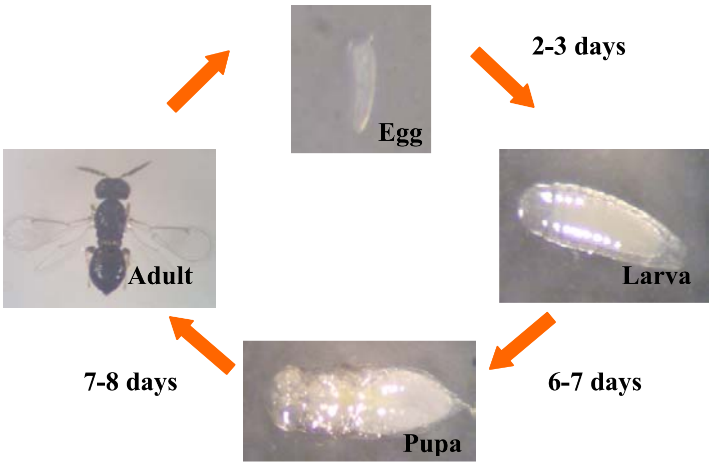


Figure 19 Life cycle of *Asecodes hispinarum* Bouček under the laboratory condition ($24\pm2^{o}C$ and $75\pm10\%$ RH).

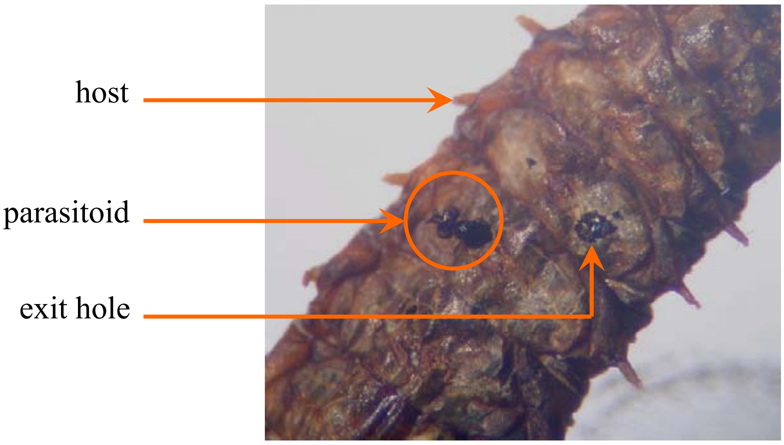


Figure 20 Parasitoids of *Asecodes hispinarm* Bouček emerged from mummified larva of *Brontispa longissima* Gestro.

6.1.2 Release of parasitoids in the field

The parasitoids can be introduced into the field as live, adult parasitoids or in the mummy stage. The introduction of parasitoids into the field in the mummy stage is the preferred option, as it allows the introduction to take place any time during the day. It is the best to do this a few days before the parasitoids are expected to emerge, as it will allow the parasitoids to become acclimatized so that they are better adapted to the local environment when they emerge from the mummy. It also enables the parasitoids to start seeking suitable *Brontispa* hosts immediately after their emergence when they are fit (Liebregts *et al*., 2006).

6.1.3 Biological control

Biological control is the action of parasitoids, predators and pathogens in maintaining the pest population density at a lower average than it would occur in its absence. Biological control by using parasitoid, predator and entomopathogenic fungus has a good chance to depress population in the field. It would decrease the use of insecticides. Biological control has recently been recognized as a promising and effective tool in the management of the most important pest on coconut palm (Sathiamma *et al*., 2001). In general, three approaches are employed in the biological control of arthropod pests: (a) important of natural enemies, (b) augmentative releases of natural enemies, and (c) conservation of natural enemies. Biological control is an important tactic in IPM systems, and should be utilized wherever it is feasible. There are several advantages to the use of biological control in comparison with other pest control tactics. Biological control only achieves partial suppression of the target pest, as a residual pest population is necessary to maintain natural enemies (Robert *et al*., 2003). Classical biological control is the control of an exotic pest species by introduced natural enemies. This involves foreign exploration, quarantine processing of collected material, mass propagation of the natural enemies, their field colonization, and evaluation of their impact on the pest population. Nearly 100 species of pest insects and weeds have been completely or substantially controlled by imported natural enemies.

6.1.4 The practice of biological control

To reflect these practices, many specialists group biological control practices into three categories: introduction, augmentation, and conservation.

- Introduction Introduction, also known as importation, is often considered the "classical" practice in biological control because most early programs used this approach. The basis for this practice is to identify the natural enemies that regulate a pest in its original location and introduce these into the pest's new location; thus, natural enemies are reassociated with their prey and hosts. The hope is that the natural enemies, once introduced, will become established and permanently reduce the pest's general equilibrium position (average population level) below the economic injury level (Pedigo, 1999). The theory of classical biological control is actually no different from that in ecology and population dynamics. A goal of many of these biological control programs is to establish a self-sustaining system (Robert *et al.*, 2003).

- Augmentation Augmentation is a biological control practice that includes any activity designed to increase numbers of existing natural enemies. These objectives may be achieved by releasing additional numbers of a natural enemy into a system or modifying the environment in such a way as to promote greater numbers or effectiveness. Therefore, the ecological result is most likely the dampening of pest population peaks, rather than significantly changing the general equilibrium position. Because of their temporary effect, these releases must be made periodically. Periodic releases may be considered as either inundative or inoculative (Pedigo, 1999).

- Inundative releases These releases depend on propagation of massive numbers of natural enemies and their widespread distribution. Subsequently, the release of the actual enemies suppresses the pest population, with little or no impact expected from progeny of the released individuals (Pedigo, 1999).

- Inoculative releases These releases differ from inundative releases in that, once they occur, the natural enemy is expected to colonize and spread throughout an area naturally. An inoculation is often made only once in the growing season, and the progeny of the released individuals have the most significant impact on the pest population (Pedigo, 1999).

- Reasons for mass rearing beneficial insects Mass rearing beneficial insects may form an important part of an IPM program. When released in suitable numbers and with appropriate timing they can help effect control of certain pest species by a variety of mechanisms (Papacek, 1995).

1. By augmenting natural populations. This is usually best carried out relatively early in the season when the beneficial insect numbers may be at a low level due to such factors as the effects of low winter temperatures or lack of availability of suitable stages of the natural host for parasitism or predation. Augmentative releases are designed to reestablish or enhance the beneficial population and may include follow-up or "booster" releases as well (Papacek, 1995).

2. By inundatively releasing into pest populations. In this example relatively large numbers of the beneficial organism are released into pest populations to effect rapid control of the target pest often timed to coincide with a specific life stage (Papacek, 1995).

3. To replenish populations of beneficially that has been adversely affected by factors such as pesticides or extreme weather conditions (Papacek, 1995).

- Conservation of natural enemies Probably the most widely practiced form of biological control is conservation of natural enemies. The objective of conservation is to protect and maintain these existing populations, particularly the insect predators and parasitoids, in an agroecosystem. Basically, this approach requires knowledge about all aspects of the natural enemy community, including species present, population numbers, phenology, and impact on pest populations in other words, the life systems of natural enemies in a given area. With this knowledge, crop production activities, including existing pest management practices, are modified to avoid natural enemy destruction. The importance of considering natural enemies of insect pests when developing pest management programs cannot be overestimated. Virtually all insect populations are affected to a certain degree by other organisms in their environment, and some of our most efficient approaches to pest management include using these organisms to our advantage. This can mean simply modifying a crop culture technique to conserve the enemies already present or supplementing their numbers with releases (Pedigo, 1999).

7. Coconut pest management

Coconut is an important crop in tropical Asia and the Pacific where more than 85% of the world coconuts are grown. The insect has caused serious losses in coconut productivity. The application of an IPM program is expected not only to help to control the insect pest, but also build capacity in emergency actions to deal with the invasive species (Changchui, 2007). The most serious insect pest of coconut palm is coconut hispine beetle, red palm weevil and rhinoceros beetle. The four elements basic to any IPM program are (a) natural control, (b) sampling, (c) economic levels and (d) a detailed knowledge of the biology and ecology of all important insects in the system. Each element is vital and provides the supporting role for all components that can be fitted into any insect pest management system. The six components of insect pest management are (a) cultural control, (b) biological control, (c) chemical control, (d) host plant resistance, (e) physical and mechanical controls, and (f) regulatory control (Watson *et al*., 1976). Therefore, it has a good impact on the environment. Additionally, this practice has a long-term impact to depress or manage the pest population on coconut plantation in low level of coconut palm damage. Actually, pest control has no intention to eliminate the pest totally but to maintain the natural balances by keeping the pest population below economic threshold level.

7.1 Pest management

Pest management is the control of pest populations, usually to reduce pest numbers at least to reach an equilibrium level, so that their effects on mankind are less harmful; to produce more crop yields and hence a better quality of life for man and animal. Pest management can reduce the use of pesticides by avoiding unnecessary chemical applications and by using nonchemical control methods whenever possible. Biological or physical control methods are beneficial in delaying the development of insecticide resistance and in reducing health risk from human exposure to pesticide (Burn *et al*., 1987). Pesticides are essentially toxic substances, but their commercial development and regulatory approval will ensure that the toxicity is directed against the pest itself and has minimal impact on the user and non-target organisms, when the pesticide is used according to the manufacturer’s instructions. The hazard from a pesticide is a product of its toxicity and the exposure (Chapman and Hall, 1990). Chemical pesticides are very useful in controlling and destroying plant pests. However, if they are not used properly, they can contaminate the environment. Serious problems are as follows: ecological imbalance, chemical residues in nature and hazard to health and sanitation (Tapinta, 1991). Additionally, chemical control may not long-term solution because of the possibility that pests would develop resistance against the commonly used insecticides and the increasing likelihood of outbreaks of secondary pests. Smith and Reynolds (1966); Dent (1995) defined IPM as a pest management system, that in the socioeconomic context of farming systems, the associated environment and the population dynamics of the pest species, utilizes all suitable techniques in as compatible a manner as possible and maintains the pest population levels below those causing economic injury. It is seen that many definitions of pest management have been defined by various workers on this topic. All the definitions mentioned three core elements: multiple tactics used in compatible manner; pests populations maintained below levels that cause economic damage; and conservation of environment quality. Thus, the collation of ideas on various definitions on IPM could be aggregated to selecting suitable technologies, integrating all feasible tactics and implementing pest control actions based on predicted ecological, economic and sociological consequences of the actions (Bottrell, 1979).

7.2 Tactics in Integrated Pest Management

Certain pest management tactics have been developed by various workers. They have three fundamentally different approaches for managing pests. One among them is manipulation of pest organisms which induces direct influence or alters behavior of pest organisms. Diseases spread prevention, use of pesticides when necessary and non-pesticidal tactics such as use of biological control, behavioral control, and physical control are some of the tools that supplement pest manipulation. The other tactic involved is crop plant manipulation which is achieved through cultural tactics and host plant resistance. The third tactic consists of environmental manipulation which is done by altering the micro-habitat and macro-habitat environment of the pests. Each tactic is discussed separately, but it should be recognized that IPM utilizes a combination of all suitable pest suppression tactics.
A control tactic that affects only the target species, and dose not harm other non-target species, is selective or specific. The method of application can be used to achieve selectivity, and is essential for management of animal pest. An additional reason why selectivity is critical for arthropod management in many situations is that it is desirable to kill the target pest but leave beneficial arthropods unharmed. Examples of beneficial arthropods include parasitoids and predators of pests that are used for biological control (Robert *et al*., 2003). The operational goals of IPM are to maintain economic viability, reduce the risk of crop loss, minimize selection pressure on pests, and to maintain the environment quality. While farmers' acceptance towards the technology package, in the end, must also be seriously taken into consideration without which the whole purpose intended for the end-users is defeated. Therefore, considering the optimum mixture of various tactics (direct and indirect) governing the feasibility at farmers, the choice of any combinations could be designed for implementation in the farmers' field. The diagram (Figure 21) represents the decision making tools and pest management tactics relatively worth enforcing in the case of the present studies.

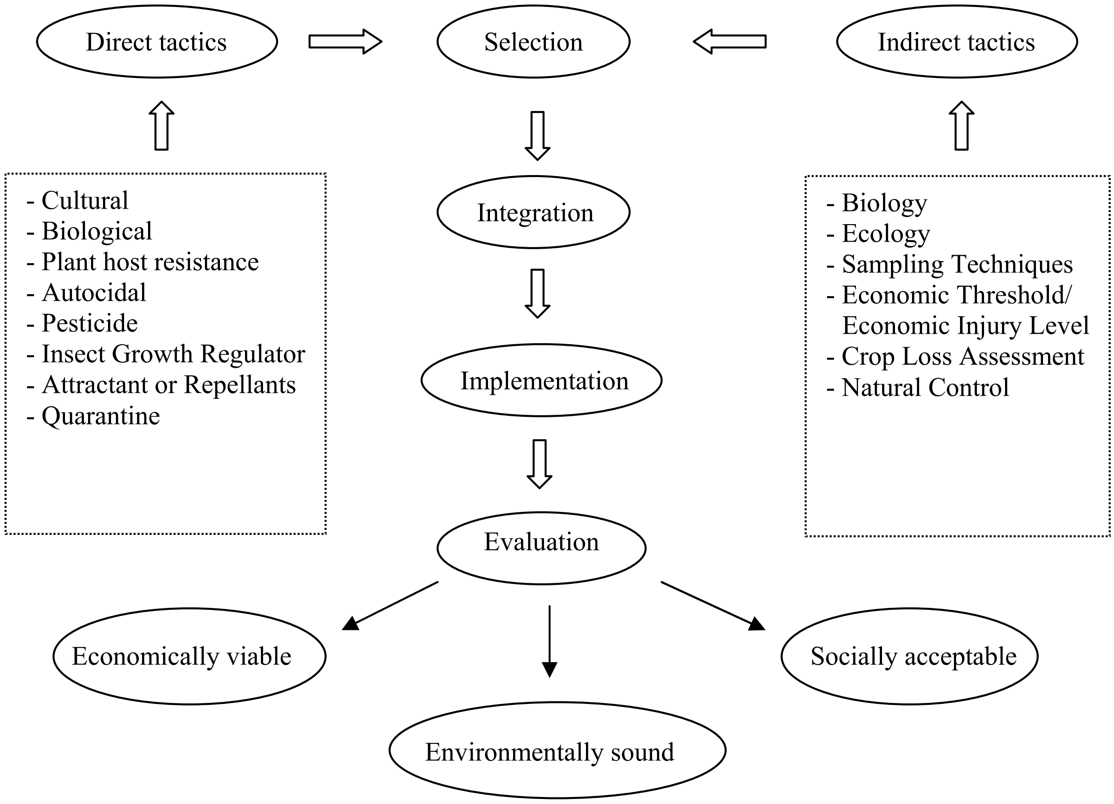


Figure 21 Components of Integrated Pest Management at implementation level.

Within the framework of program designing, use of decision making tools needs certain types of information which are needed to develop an IPM program based on the understanding of the biology and ecology of the system, the economics, and the social implications (Ngawang, 2005).

7.3 Implementation of Pest Management

A comprehensive IPM program for an agricultural system requires willing and cooperative growers and dedicated research and extension personnel who can produce a body of relevant information concerning farming practices, pest biology, and pest management tactics. IPM is a challenging educational subject because of its complexity and intensive emphasis on management, which requires that individuals who wish to apply it understand broader ecological relationships in addition to crop production practices. Rather than simply treating pests when they occur or preventatively, IPM emphasizes monitoring of pests, natural enemy population levels, and crop status throughout the season, and applies control measures only when pest abundance is sufficient to cause unacceptable economic loss relative to the cost of control. In addition, IPM tactics include a variety of agents and materials for pest population suppression which may not be promoted through commercial enterprises (Robert *et al*., 2003). Many studies, such as those of Rogers (1983) have considered the adoption of agricultural innovations, but until recently, there were relatively few studies focusing on the implementation process specifically for IPM, including incentives for and constraints to adoption. Future, the degree to which IPM is implemented on a specific crop can vary as growers may modify innovations to fit their needs, a process termed “adaptive implementation” or “reinvention”. IPM is one promising approach for a sustainable management of coconut plantations and could be capable to control and reduce pest populations.

MATERIALS AND METHODS

Part 1 Mass rearing and biological study of *Asecodes hispinarum* Bouček

The rearing of hosts insects and parasitoids were conducted under laboratory conditions in a temperature-controlled room at 25±2^{o}C and 70±10% RH with natural lighting at the Plant Protection Research and Development Office in Bangkok, during July 2006 to December 2007.

1.1 Stock culture of host insects and parasitoids

The cultures of hosts, *Brontispa longissima* Gestro, were collected from infested coconut palms in Prachuap Khiri Khan Province. The hosts were kept in plastic boxes (14 cm length × 10 cm width × 6 cm high, rearing box) covered with ventilated lids. One hundred pairs of male and female were maintained per box and it was necessary to add new adults to replace the dead ones. Inspection and collection of eggs were made every two days; eggs were removed and transferred to new leaves. Coconut leaves were sprayed with 10% Clorox ® (0.1% sodium hypochlorite) and wiped with a clean cloth before used. The leaves used for rearing were cut into pieces of 11-12 cm long and were replaced every two days. Five hundred 3rd instar larvae or older were transferred to new rearing box with coconut leaves using paintbrush. This required careful inspection every two days and old leaves were replaced with fresh ones (Figure 22).

The cultures of parasitoids, *Asecodes hispinarum* Bouček were kept in rearing box but covered with a fine nylon cloth. Twenty 4th or 5th instar *B. longissima* larvae on cutting pieces of coconut leaves were used as hosts for parasitoids. A piece of tissue paper (3 cm length × 1 cm width) soaked with diluted honey (50% honey w/v) was provided as food for adult parasitoids in this experiment. Sixty parasitoids were introduced into each rearing box. After 24 hours (hrs), these parasitoids were collected and transferred into new boxes. The parasitized hosts became less active and turned to brown color after 6-7 days. At this stage, they were isolated individually into small vials (1.5 cm in diam., 4.5 cm long), and kept as stock of parasitoid. *A. hispinarum* was allowed to parasitize every two days. The parasitoids emerged after 18-20 days (Figure 23).

Figure 22 Mass rearing of *Brontispa longissima* Gestro.

a) Spraying 10% Clorox ® (0.1% sodium hypochlorite) on the cloth and wipe to clean the coconut leaves.

b) The coconut leaves were cut into small pieces of 12 cm long.

c) Pile of coconut leaves about 20 pieces.

d) Adults of *Brontispa longissima* Gestro were placed at 100 males and 100 females per box (1:1).

e) Eggs were scraped from old leaves and transferred to new ones.

f) Scraped eggs were transferred to new leaves arranged in pile and kept until hatching.

g) Newly emerged larvae were maintained in the new box for further rearing with fresh leaves.

h) Prepare a new box with fresh leaves every two days; allow the larvae to feed on new leaves until larvae became third instar.

i) Coconut leaves tied together with rubber band mimicing unopened coconut leaves.

j) Transferring larvae age after third instar by using paintbrush to new leaves.

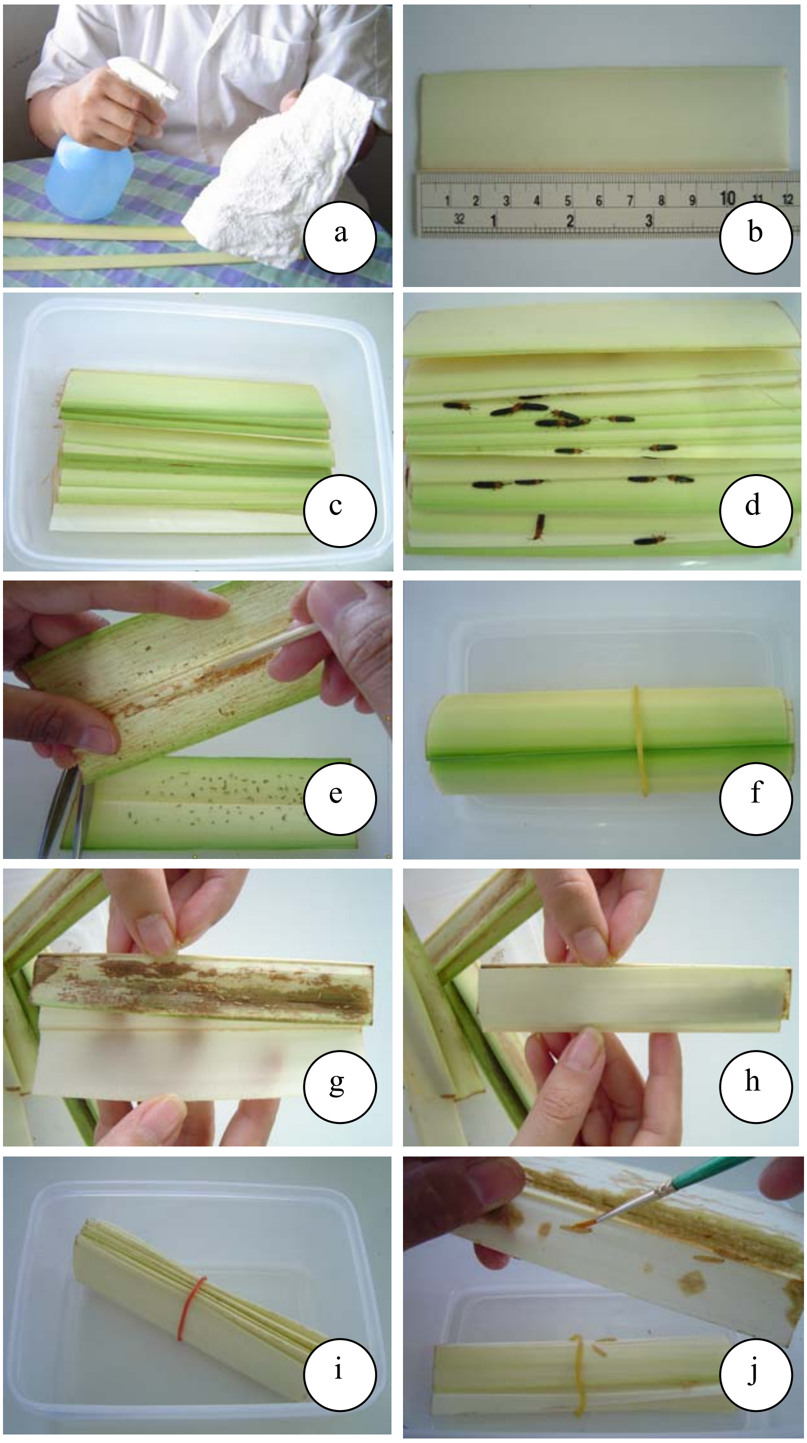

a
b
c
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Figure 23 Mass rearing of *Asecodes hispinarum* Bouček on *Brontispa longissima* Gestro.

a) Selected hosts, *Brontispa longissima* Gestro, about 7-8 larvae per cut leaves, totaling 20 larvae per box.

b) Paste a piece of soaked tissue paper (3 cm length × 1 cm width) with 50 % honey (w/v) on inner-side of rearing box.

c) Adults of *Asecodes hispinarum* Bouček in container.

d) Aspirator for sucking *Asecodes hispinarum* Bouček.

e) Rearing box with parasitoids.

f) Dipping the mummified larvae into the 10% Clorox ® (0.1% sodium hypochlorite) to prevent fungus growing.

g) Placing the mummified larvae into container for continuous rearing.

h) Isolate individually mummified larvae into small vials for various experimental purposes.


a
b
c
d
e
f
g
h

1.2 Effect of temperature on longevity of adult parasitoids *A. hispinarum*

Longevity of adult males and females were studied at four temperatures (22±0.5, 25±0.5, 28±0.5 and 31±0.5^{o}C). Males and females were tested separately. The newly emerged parasitoids were placed singly in glass vials (1 cm in diam., 5.5 cm long, with a cotton lid), provided with water, and diluted honey (50% honey w/v) in a piece of soaked cotton bud. The parasitoids were assigned to a temperature-controlled incubator (Figure 24), (80±5% RH; 12:12 [L:D]). They were checked daily for the number of mortalities. The honey and water were replaced as needed. From each culture, 20 males and 20 females parasitoids were tested at each treatment. Each treatment was replicated five times.

Figure 24 Temperature-controlled incubator Sanyo (MIR-153).

1.3 Host searching and oviposition behavior of *A. hispinarum*

Host searching and oviposition behavior of *A. hispinarum* were studied under no-choice conditions using fourth instar larvae of *B. longissima*. This experiment was carried out in rearing box containing 20 larvae. The parasitoid's behavior was observed directly. The activities of parasitoids were recorded. The oviposition behavior of 20 wasps was observed as replication.

1.4 Host specificity of *A. hispinarum* testing

There were six types of fourth instar larvae in each box. Each rearing box had 10 larvae. The larvae in each rearing box were fed by different food. The larvae of beet armyworm (*Spodoptera exigua* Hübner) were fed by an artificial diet. The larvae of honey bees (*Apis florae* F.) were fed by honey. The larvae of silkworm (*Bombyx mori* L.) were fed by *Morus alba* L. leaves. The larvae of lady beetle (*Nephus ryuguus* H. Kamiya) were fed by *Cucurbita pepo* L., The larvae of coconut leaf beetle (*Plesispa reichei* Chapuis) and coconut hispine beetle (*Brontispa longissima* Gestro) were fed with coconut leaves. Subsequently, the 40 female parasitoids with diluted honey (50% honey w/v) as a food of parasitoid were put into the rearing boxes. The boxes were kept in a temperature-controlled incubator (25±0.5^{o}C, 80±5% RH; 12:12 [L:D]). After 24 hrs, the release parasitoids were removed. The larvae of each host were reared until parasitoid emergence or normal pupation took place. Observation for mummified larvae of host and the number of mummified larvae was recorded. The number of days from oviposition on host to adult emergence and the number of wasps emerging from each host stage were counted. The tests were replicated 10 times for each host species.

1.5 Fecundity study of *A. hispinarum*

Adult fecundity was determined by lifetime egg deposition. Newly emerged male and female were collected and held together for six hours. The mated females were individually isolated in ventilated plastic boxes (4.5 cm in diam., 4 cm long) and fed with diluted honey (50% honey w/v) in a piece of soaked tissue (1.5 cm length × 1 cm width). Each box had five larvae of *B. longissima*, primarily in the fourth instar developmental stage. The female parasitoid was transferred to a set of hosts daily throughout her lifetime. The 30 boxes of parasitoid were kept in a controlled incubator. Dissected hosts from each box and the numbers of laid eggs per host were recorded.

Part 2 Biological control study of *A. hispinarum* under laboratory conditions

2.1 Suitable exposure time of parasitoids, *A. hispinarum* to hosts, *B. longissima*

Preferred exposure time for parasitization by *A. hispinarum* was studied in a controlled incubator. For each study, 20 fourth instar larvae of hosts were used. Forty mated female parasitoids were placed in a rearing box fed with diluted honey (50% honey w/v) for 3, 6, 12, 24 hrs and its lifetime. The parasitoids were removed after exposure time was completed. The developmental stages of parasitized larvae, the percentage of parasitization and percentage of parasitoid emergence were recorded. Each treatment was replicated 10 times. Twenty mummified larvae were sampled for recording the number of emerged male and female parasitoid.

2.2 Suitable number of parasitoid, *A. hispinarum* per twenty hosts, *B. longissima*, for mass rearing of parasitoid

The suitable number of female parasitoids *A. hispinarum* on parasitization was tested under a controlled incubator. For each trial, 20 fourth instar larvae were used. Different number of mated female parasitoids (10, 20, 40, 60 and 80) were placed in rearing box and fed with diluted honey (50% honey w/v). After 24 hrs, the parasitoids were removed. The developmental stages of parasitized larvae, percentage of parasitization and percentage of parasitoid emergence per mummified larvae were recorded. Each treatment was replicated 10 times. Twenty of mummified larvae were sampled to determine the number of emerged male and female of parasitoid.

2.3 Effect of temperature on developmental time and parasitization *A. hispinarum*

The developmental time of immature stages of *A. hispinarum* was studied at four temperature regimes (22±0.5, 25±0.5, 28±0.5 and 31±0.5°C). For each temperature regime, the study was divided into two parts. The first part, the total of 200 fourth instar larvae of *B. longissima* were exposed to 400 mated females of *A. hispinarum*. After 24 hrs, the parasitoids were removed. For each study, ten host larvae were collected daily for dissection and observed the parasitoid development. The second part, the parasitization was studied at different temperatures. Twenty 4th instar larvae of host were exposed to 40 mated parasitoids and fed with honey for a 24 hrs period. The parasitoids were removed after one day. Percentage of parasitization and number of adult parasitoid emergence per mummified larva was recorded. Each study was replicated 10 times. Random samples of 20 mummified larvae were checked and recorded for the number of emerged males and females. Twenty newly females per treatment were randomly selected and dissected in a saline solution. The numbers of eggs produced under different temperatures was then recorded.

2.4 Host age preference and their effect on parasitization, parasitoid emergence, percentage of female *A. hispinarum* emergence and number of eggs from virgin female parasitoid

Experiments were conducted to determine the stages of immature host, *B. longissima*, that would support successful growth and development of parasitoid, *A. hispinarum*.

2.4.1 No-choice test

In no-choice test, first to fourth instar larvae of host were used. Twenty host larvae of each instar were placed in rearing box and exposed to 40 mated female parasitoids fed with diluted honey (50% honey w/v). The boxes were kept in a controlled incubator. Parasitoids were removed after 24 hrs. Host larvae were reared with excessive food until parasitoid emergence. The number of days from oviposition to adult emergence was recorded. Parasitization rate on each larval stage was recorded from ten replicates. Random samples of 20 mummified larvae were observed and recorded for the number of emerged male and female parasitoid, the body length and length of right forewing. Random samples of 20 newly emerged females were dissected in a saline solution and the number of eggs was recorded.

2.4.2 Choice test

This experiment was similar to no choice test. However, ten larvae from each stage were placed together in each rearing boxes. Each experiment was replicated 10 times.

2.5 Effect of alternative host plant of *B. longissima* on parasitization, parasitoid emergence, percentage of female *A. hispinarum* emergence and number of eggs from virgin female parasitoid

Experiments were conducted to determine whether rearing *B. longissima* on an alternative food plant had any effects on *A. hispinarum* development.

2.5.1 No-choice test

In no-choice test, *A. hispinarum* was allowed to oviposit in larvae that fed with coconut leaves or typhus leaves, *Typha angustifolia* L. Twenty *B. longissima* larvae were placed in rearing boxes. Subsequently, 40 mated female parasitoids were released in the rearing boxes. The boxes were kept in a controlled incubator. After 24 hrs, the parasitoids were removed. The number of days from oviposition to parasitoid adult emergence was recorded. The study was replicated 10 times with new parasitoids. There were 10 replications for each host stage studied from both food plants. Twenty mummified larvae were randomly, picked up for recording wasp emergence and from these twenty emerged females were dissected to check and record the number of eggs from virgin female parasitoid in each female.

2.5.2 Choice test

For the choice test, parasitoids were released at the middle of rearing boxes with three separate compartments containing *B. longissima* reared on coconut and typhus leaves on the left and right side (Figure 25). Ten fourth instar larvae of *B. longissima* were placed in a rearing box. Each treatment was replicated 10 times.

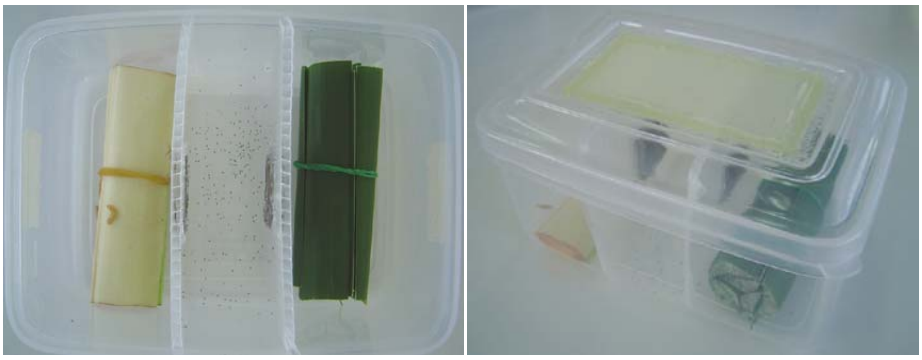

Figure 25 Three separate compartments containing *Brontispa longissima* Gestro reared on coconut and typhus leaves on the left and right side. The parasitoid, *Asecodes hispinarum* Bouček was released at the middle.

Part 3 Pest management program for major insect pests of coconut in a golf course

Pest management program experiment was conducted out at Panya Indra golf course, Bangkok during January 2007 to March 2008. The area had approximately 1,800 coconut trees. This experiment was aimed to study the feasibility of coconut pest management program in the golf course. The main pests were the coconut hispine beetle, red palm weevil and rhinoceros beetle. After implementation of pest management for one year, the damage level was compared. The data were basic information for further development of pest management program in the golf course.

3.1 Implementation of coconut pest management

The implementation of coconut pest management in the golf course was to specifically control the main pests, i.e., coconut hispine beetle, rhinoceros beetle and red palm weevil (Table 3). Pest management activities were as follows:

1. Evaluate the general damage situation before Integrated Pest Management (IPM) program was started.
2. Survey the coconut palm in the golf course to identify the key insect pests.
3. Survey the distribution of coconut hispine beetle, rhinoceros beetle and red palm weevil in the golf course.
4. Sanitation would be used to destroy the existing breeding sites of the coconut hispine beetle, red palm weevil and rhinoceros beetle around the golf course.
5. Cut the coconut tree destroyed by the red palm weevil.
6. Set up the attractive traps for red palm weevil and rhinoceros beetle around the golf course.
7. Weekly collect and record the beetle in traps for one year.
8. Use of fungus, *Metarhizium anisopliae* to control rhinoceros beetle in manure pits.
9. Survey rhinoceros beetle population in manure pits every three months.

10. Control the spread of coconut hispine beetle in area using *A. hispinarum* by releasing mummified larvae on monthly basis.

11. Rapid damage survey and randomly check 20 unopened coconut leaves (spear). Count all coconut hispine beetle life stage and record percentage of parasitization by *A. hispinarum* per spear to check establishment of parasitoid in the golf course on monthly basis.

12. Sample the presence of coconut hispine beetle, rhinoceros beetle and red palm weevil every month. A field survey methodology of coconut hispine beetle, similar to that used by Department of Agriculture (DOA) was designed to monitor insect pest abundance.

13. Compare the distribution of beetles on golf course before and after one year.

14. Evaluate the success of IPM program.

Table 3 Implementation of IPM program for major coconut insects at Panya Indra golf course during January 2007 to March 2008.

Action Performed	Months														
	Jan '07	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec '07	Jan '08	Feb	Mar' 08
Brontispa longissima Gestro															
- Evaluatation infested coconut palms.	←	—	—	—	—	—	—	—	—	—	—	→			
- Mass rearing of parasitoid, *Aesodes hispinarum* Bouček	←	—	—	—	—	—	—	—	—	—	—	→			
- Releasing parasitoids.	←	—	—	—	—	—	—	—	—	—	—	→			
- Selection of infested 20 spears to checked percentage of parasitization.	←	—	—	—	—	—	—	—	—	—	—	→			
- Checking population by random 20 spears to check population.	←	—	—	—	—	—	—	—	—	—	—	→			
Rhynchophorus ferrugineus Oliver															
- Order pheromone lures.	←	—	→												
- Making pheromone buckets.		←	→												
- Setting pheromone traps totally 10 traps.		←	→												
- Collecting the beetles in traps every week.				←	—	—	—	—	—	—	—	—	—	—	→
- Surveying damage of the coconut palms and cutting off.				←	—	—	—	—	—	—	—	—	—	—	→
Oryctes rhinoceros L.															
- Order pheromone lures.	←	—	→												
- Order fungus *Metarhizium anisopliae*	←	—	→												
- Making manure pit totally 10 pits.		←	→												
- Making pheromone buckets.		←	→												
- Collecting the beetles in traps every week.				←	—	—	—	—	—	—	—	—	—	—	→
- Checking percentage infested of beetles in manure pits.							↔				↔				↔

Table 3 (Continued)

Action Performed	Months														
	Jan ’07	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec ’07	Jan ‘08	Feb	Mar’ 08
Oryctes rhinoceros L. (continued)															
- Evaluatation of infested coconut palms.				←	—	—	—	—	—	—	—	—	—	—	→

3.2 Control of coconut hispine beetle, *Brontispa longissima* Gestro

Grading of overall damage caused by *B. longissima* on the 1st-10th leaves was performed monthly from every tree in the area. Damage levels on coconut leaves were assessed according to five grading categories: Grade 0 = no damage; Grade A = slight damage 1-25%; Grade B = medium damage 26-50%; Grade C = high damage 51-75%; Grade D = severe damage 76-100% (Sindhusake *et al*., 2006). The evaluation of damage levels of newly opened coconut leaves were assessed using the same grading categories already mentioned. All possible breeding sites of *B. longissima* around the area were treated with biological control agent of larval parasitoid, *A. hispinarum*. Continuous releases were made in and around the area from January, 2007 until the end of the same year. The numbers of parasitoid released (mummified host larvae) were based on density of damage on coconut trees. The release rate at five mummified larvae per rai per month was chosen (1 rai = 0.16 hectare) (Winotai *et al*., 2007). Releasing was made by putting five mummified larvae of *B. longissima* in plastic tube (1.5 cm in diam., 4.5 cm long) into which five holes were made for parasitoids’ exit. The establishment of larval parasitoids was checked by observing from 20 selected infested spear leaves. The eggs, larvae, pupae and adult beetles from each sample were kept individually in the rearing box for two weeks and evaluated for the presence of parasitoids. The percentage of parasitization by *A. hispinarum* in the field was checked by collecting and rearing *B. longissima* until parasitoid emergence. The emerged parasitoids were classified and the death of larvae or pupae and emergence of the parasitoids were recorded. Population of *B. longissima* was also evaluated from 20 randomly sampled spear leaves.

Figure 26 Containers used for releasing parasitoids, *Asecodes hispinarum* Bouček in golf course.

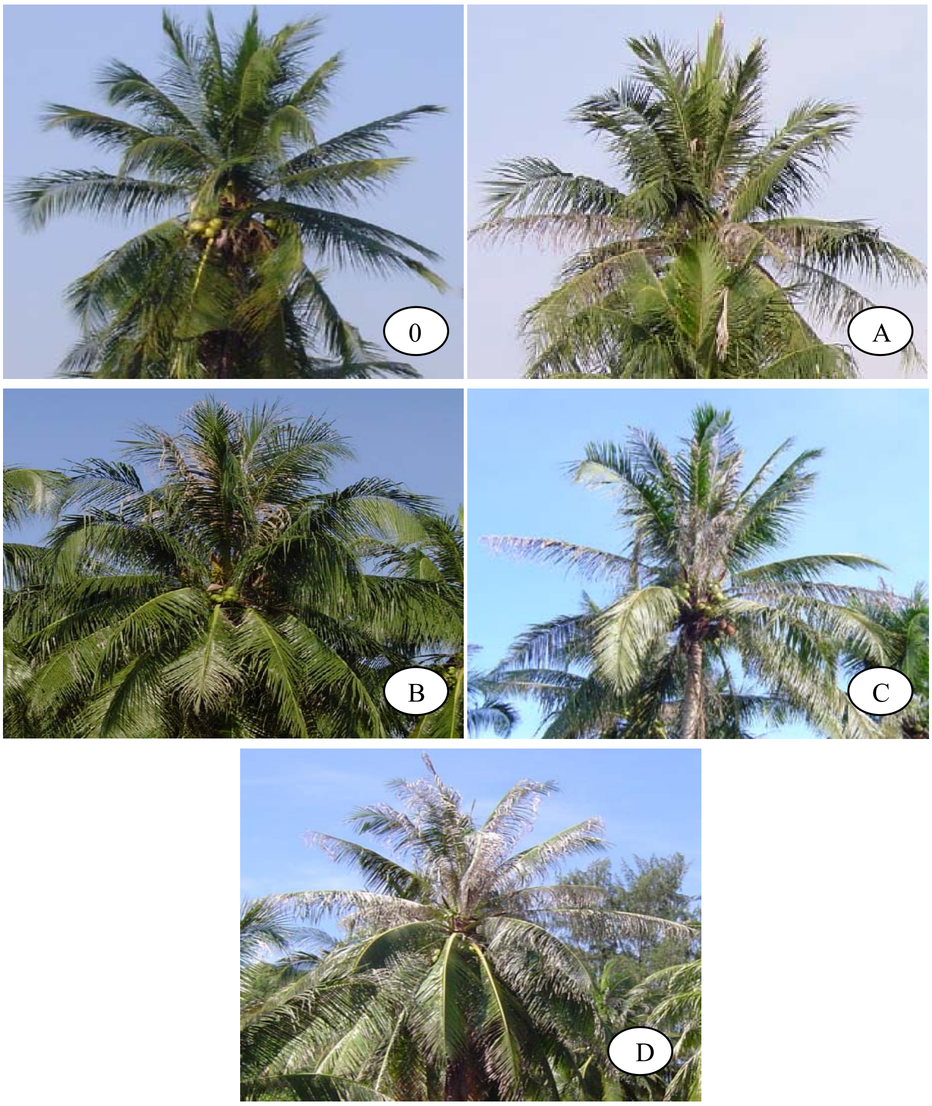

Figure 27 Damage levels caused by *Brontispa longissima* Gestro observed from the 1^{st}-10^{th} coconut leaves.

0) Grade 0 = no damage

A) Grade A = slight damage 1-25%.

B) Grade B = medium damage 26-50%.

C) Grade C = high damage 51-75%.

D) Grade D = severe damage 76-100%.

3.3 Control of red palm weevil, *Rhynchophorus ferrugineus* Oliver

Red palm weevil population were controlled by sanitation and pheromone trap. The method of cultural control bagan by observing the upper leaves of coconut. When the upper leaves turned brown, the reddish liquid oozed out and dripped down the trunk, trees were cut as soon as possible to eliminate a possible breeding site for red palm weevil (Figure 28). The pheromone lures of red palm weevil were manufactured by Chem Tica International S.A., Costa Rica (Figure 29). The components of this pheromone lures were 4-methyl-5-nonanl (9 parts) and 4-methyl-5-nonanone (1 part) – purify 99.9% + 0.1% colorant and 0.1% antioxidant. Both components of more than 95% had a released rate of 3-10 mg per day; the lure has 700 mg of mixture. The pheromone traps consisted of five liters plastic bucket with a cover having four opening 1.5×4 cm. The sides of bucket have four opening 3×5 cm for the entrance of the attracted adults. The pheromone was embeded in special plastic that allowed the release of the pheromone slowly and at a constant rate. The bucket was covered from the outside by plastic net to allow adult weevils to crawl up easily into the openings. The pheromone traps were buried effectively nearby the coconut tree (Figure 30). A total of 10 traps were set around the golf course. The distance between the trap was approximately one kilometer. The pheromone lure were changed every three months.

Figure 28 Cutting of the coconut tree when destroyed by *Rhynchophorus ferrugineus* Oliver.

Figure 29 Pheromone lures for *Rhynchophorus ferrugineus* Oliver.

Figure 30 Installation of the pheromone traps of *Rhynchophorus ferrugineus* Oliver.

3.4 Control of rhinoceros beetle, *Oryctes rhinoceros* L.

The control of rhinoceros beetle in the golf course was performed using pheromone and entomopathogenic fungi. The percentage of damage by the rhinoceros beetle on leaves was obseved before the initiation of the experiment. IPM practices by application of metarhizium, *Metarhizium anisopliae* (Metch) Sorock in manure pits (2×2×0.5 meters) providing as attractant traps were implemented. The fungus was produced in laboratory through the use of corn cereal. This experiment used fungus from the Department of Agriculture Extension. The fungus was used at the rate of two kilograms of cereal per pit when green spores had developed. A layer of cow-dung and coconut fuzz (1:3) was spread uniformly in 10 manure pits around the field edge. Water was sprinkled regularly to keep the substrate at 60-70% moisture. The surface was mulched with coconut leaves to prevent moisture loss (Figure 31). The pheromone-rhinolure (SPLAT-RB) of rhinoceros beetle manufactured by ISCA Technologies, Inc., USA (Figure 32) was also used. The component of this pheromone lure was ethyl-4-methyloctanoate. The pheromone trap consisted of one bucket (15 liters) with vanes that effectively captured rhinoceros beetle. Vanes were protruded into bucket about 20 cm from the bottom. This prevented beetles from flying out. The lures were positioned in the center of trap vanes secured in the bucket. A single application of SPALT-RB dollop weighed approximately four grams was used for each trap. The SPLAT-RB dollop was applied to achieve a round shape, as opposed to a string shape. Drain holes in the bucket prevented the accumulation of rainfall. Traps were suspended 2-3 meters above the ground by hanging on coconut trees or put on a roof of shelter (Figure 33). New lures were added until the number of beetles caught decreased to zero or to a very low number. The experiment was carried out for a period of 12 months, from April 2007 to March 2008. The pheromone traps were monitored weekly and numbers of male and female beetles were recorded. The total of 16 pheromone traps was set around the golf course. The distance between the traps was approximately 500 meters. The collected data were recorded as the percentage of damage by the rhinoceros beetle on leaves during 12 months.

Figure 31 Method of manure pit for control *Oryctes rhinoceros* L.

a) Mixing Cow-dung and coconut fuzz (1:3).

b) Sprinking water to keep the substrate at 60-70% moisture.

c) Strewing *Metarhizium anisopliae* in manure pit.

d) Covering manure pit with coconut leaves.

Figure 32 Pheromone lures for *Oryctes rhinoceros* L.

Figure 33 Installation of the pheromone traps of *Oryctes rhinoceros* L.

Statistics

Data were subject to analysis of variance (ANOVA) to determine differences between means. Wherever significant differences occurred, Tukey's multiple range tests (three or more treatments) or *t* tests (two-way comparisons) were applied for mean separation. Results are presented as means per treatment (±SD), where means within the same column followed by different letters are significantly different. The significance level was set at $P = 0.05$.

RESULTS

Part 1 Mass rearing and biological study of *Asecodes hispinarum* Bouček

1.1 Stock culture of host insects and parasitoids

The result of rearing management was shown in Table 4. For host insect, *Brontispa longissima*, the average percentage of egg hatching was 67.37%, the average percentage of surviving larvae was 78.31% and the average number of fourth of *B. longissima* produced per month was 5,574 larvae. At the fourth instar, *B. longissima* larvae would be exposed to parasitoids. The stock parasitoids were allowed to parasitize every two days; a monthly averaged of 1,400 larvae of *B. longissima* were parasitized. The average percentage of parasitization was 84.30% and percentage of survival of adult parasitoids was 77.73%. The rearing of parasitized host for about seven days caused the larvae to turn to a dark brown color and became mummified larvae.

1.2 Effect of temperature on longevity of adult parasitoids *A. hispinarum*

Study of adult longevity at 22, 25, 28 and 31^{o}C showed that females and males *A. hispinnarum* longevity were different. Life span of adult male was shorter than that of female (Table 5). Adult longevity was longest at 22^{o}C and shortest at 31^{o}C. At 22^{o}C, females fed with honey lived longest (4.9±1.36 days) while fed males lived only 3.53±1.34 days. Providing adults with water alone or with no food, significantly decreased longevity.

Table 4 Production of fourth instar larvae of *Brontispa longissima* Gestro for rearing larval parasitoid, *Asecodes hispinarum* Bouček under laboratory conditions (25±2^{o}C, 70±10% RH, natural lighting) during January to December 2007.

Month	*B. longissima*			*A. hispinarum*	
	% Hatchability of eggs	% Survival larvae	Total no. of fourth instar larvae produced	% Parasitism	% Survival adult parasitoids
January	78.52	88.50	5,263	87.86	83.90
February	69.73	84.40	5,019	86.07	81.00
March	56.84	72.50	4,771	81.00	76.10
April	43.54	71.60	4,805	84.57	60.47
May	46.24	63.70	4,754	78.93	66.52
June	63.68	74.80	5,784	80.36	77.87
July	73.91	71.40	5,932	81.29	81.11
August	72.58	74.30	5,678	89.29	78.72
September	74.52	85.70	6,312	84.57	84.80
October	73.12	79.80	5,425	89.71	75.88
November	79.45	82.40	6,422	81.43	80.09
December	76.32	90.60	6,728	86.50	86.29
Average	67.37	78.31	5574.42	84.30	77.73
SD.	12.24	8.17	681.84	3.66	7.51

Table 5 Effect of various temperatures on adult longevity of male and female *Asecodes hispinarum* Bouček with different food supplies at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok (n=100, 80±5% RH).

Temperature (^{o}C)	Adult longevity (days)					
	No food		Water		50% Honey (w/v)	
	Male	Female	Male	Female	Male	Female
22	2.42±0.78d	2.75±0.74d	2.52±0.78d	2.95±0.67d	3.53±1.34d	4.90±1.36d
25	1.73±0.45c	2.06±0.66c	1.80±0.40c	2.20±0.64c	2.83±1.28c	3.82±1.18c
28	1.43±0.51b	1.63±0.49b	1.35±0.48b	1.66±0.48b	2.21±0.91b	2.89±1.01b
31	1.02±0.14a	1.02±0.14a	1.00±0.00a	1.03±0.17a	1.13±0.34a	1.26±0.44a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey’s multiple range tests.

1.3 Host searching and oviposition behavior of *A. hispinarum*

After adult parasitoids emergence, they usually started walking around the leaves without any apparent direction, drumming the leaf surface with their antennae. This is searching behavior. Searching continued until the wasp encountered a host. Upon encountering a host larva, the wasp carefully examined it by drumming with antennae. If the female parasitoids accepted the host after examination, they began to parasitize the host larvae (Figure 34). The adult female walked around the host larva before attacking by grasping a host larva with its legs and folded her abdomen downward, and then inserted the ovipositor into the host. During this process, the ovipositor was directed either to the anterior, the middle, or the posterior part of the larva, sometimes in several attempts. After a successful attack by the insertion of ovipositor insertion or stinging, the wasp withdrew its ovipositor and walked away. The parasitization was completed within 35.88±18.9 minutes. The larvae *A. hispinarum* fed inside the host larva until emergence. The adult *A. hispinarum* came out from the host larva by making an emergence hole (Figure 35).

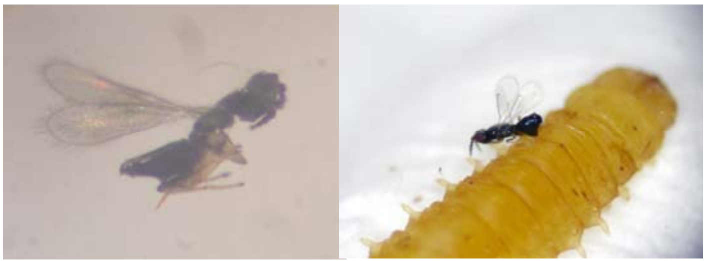

Figure 34 *Asecodes hispinarum* Bouček parasitizing on *Brontispa longissima* Gestro larva.

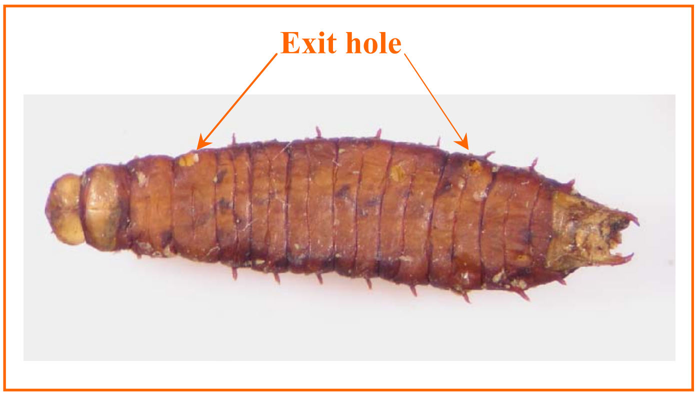

Figure 35 Mummified larvae of *Brontispa longissima* Gestro with emergence hole of parasitoid.

1.4 Host specificity of *A. hispinarum* testing

Host specificity of *A. hispinarum* has been tested on larvae of beet armyworm (*Spodoptera exigua*), honey bees (*Apis florae*), silkworm (*Bombyx mori*), lady beetle (*Nephus ryuguus*), coconut leaf beetle (*Plesispa reichei*) and coconut hispine beetle (*Brontispa longissima*). The results showed that the parasitoid did not attack any testing species except the larvae of *B. longissima* and *P. reichei* (Table 6). This was the first record that *A. hispinarum* could parasitized other larvae besides *B. longissima* (Figure 36). The length from head to abdomen (body length) of parasitoids reared on *B. longissima* was significantly longer than those reared on *P. reichei* (Table 7). The male adults of parasitoid reared on *B. longissima* and *P. reichei* were 0.83±0.02 mm. and 0.64±0.02 mm., respectively. While the body length of female reared on *B. longissima* and *P. reichei* were 0.93±0.03 mm. and 0.69±0.03 mm., respectively. Mummified larvae produced more female parasitoids than male for *B. longissima* and the same trend was observed for *P. reichei*. The percentage of parasitization, the percentage of emergence and the number of eggs from virgin female parasitoid when reared on *B. longissima* was higher than those reared on *P. reichei* (Table 8).

Table 6 Average number of mummified larvae and normal pupae of six host insects after exposure to parasitoid, *A. hispinarum* under laboratory conditions at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007 (*n*=10).

Hosts insects	No. of mummified larvae	No. of normal pupa
Spodoptera exigua	0.0	6.3±0.95
Apis florae	0.0	3.2±0.79
Bombyx mori	0.0	6.7±1.16
Nephus ryuguus	0.0	4.3±095
Brontispa longissima	7.8±0.92	0.0
Plesispa reichei	4.1±1.10	0.0

Table 7 Comparative body length and length of forewing of adult parasitoids, *Asecodes hispinarum* Bouček reared on *Brontispa longissima* Gestro and *Plesispa reichei* Chapuis under laboratory conditions at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007 (*n*=10).

Parasitoids reared on different hosts	Body length (mm.)		Length of forewing (mm.)	
	Male	Female	Male	Female
B. longissima	0.83±0.02b	0.93±0.03b	0.57±0.01b	0.72±0.02b
P. reichei	0.64±0.02a	0.69±0.03a	0.47±0.01a	0.53±0.03a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey’s multiple range tests.

Table 8 Parasitization on *Brontispa longissima* Gestro and *Plesispa reichei* Chapuis by female *Asecodes hispinarum* Bouček from host specificity test at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007.

Host species	% Parasitization	% Parasitoid emergence	% Female	No. of eggs from virgin female parasitoid
B. longissima	78.00 ± 9.19b	75.44 ± 4.83b	70.95 ± 1.95a	45.50 ± 9.00b
P. reichei	41.00 ± 11.01a	34.17 ± 8.21a	72.13 ± 10.83a	12.70 ± 4.81a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

Figure 36 Mummified larvae rearing on different host species.

1.5 Fecundity study of *A. hispinarum*

Thirty female parasitoid adult, *A. hispinarum* were used for fecundity test. On the first day, an average number of eggs per female was 55.54±10.94 eggs with the range of 35-77 eggs. Only 14 female parasitoid adults were survive and all adult died on third day. An average number of eggs on the second day was 36.21±10.37 eggs, with range of 20-55 eggs. Total average number of eggs per female was 49.39±14.01 eggs, with range of 20-77 eggs (Table 9).

Table 9 Number of eggs per mummified larvae of first and second days.

Day	*n*	Average no. of eggs	Range
First day	30	55.54±10.94	35-77
Second day	14	36.21±10.37	20-55
Total	44	49.39± 14.01	20-77

Part 2 Biological control study of *A. hispinarum* under laboratory conditions

2.1 Suitable exposure time of parasitoids, *A. hispinarum* to hosts, *B. longissima*

Exposure time of host larvae to adult parasitoids showed an effect on the percentage of parasitization. Parasitization was lowest when exposure time was three and six hours. The optimal time for exposure should be longer than 24 hrs. The percentage of parasitoid emergence and percentage of female parasitoid emergence per host were not affected by exposure times (Table 10).

Table 10 Effects of exposure time *Asecodes hispinarum* Bouček on *Brontispa longissima* Gestro at variable times with controlling temperature 25±0.5^{o}C and 80±5% RH at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007.

Exposure time between parasitoids and hosts (hrs.)	% Parasitization (*n* = 10)	% Parasitoid emergence (*n* = 10)	% Female (*n* = 20)
3	60.50±6.43a	82.73±4.01a	70.27±3.13a
6	66.00±5.68a	82.65±5.75a	69.73±4.11a
12	76.50±5.81b	84.31±5.25a	70.69±5.11a
24	87.00±6.32c	85.11±4.40a	70.91±4.02a
Lifetime	87.50±4.25c	83.41±6.25a	70.51±2.31a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

2.2 Suitable number of parasitoid, *A. hispinarum* per twenty hosts, *B. longissima*, for mass rearing of parasitoid

Number of female parasitoids ranging from 10 to 80 females affected parasitism rate. The percentage of parasitization was highest at 40 and 60 females, so the optimal female parasitoids for parasitization should be 40 and 60 females per twenty hosts. The parasitization efficiency of *A. hispinarum* decreased with increasing number of *A. hispinarum*. The percentage of parasitoid emergence and percentage of female parasitoid emergence per host were not different among number of female parasitoids (Table 11).

Table 11 Density effect of female parasitoids, *Asecodes hispinarum* Bouček on parasitization at 25±0.5°C and 80±5% RH at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007.

No. of female parasitoids per 20 hosts	% Parasitization (n = 10)	% Parasiotoid emergence (n = 10)	% Female (n = 20)
10	51.50±5.31a	85.25±5.56a	70.72±4.62a
20	67.00±6.75b	85.22±4.41a	68.34±4.47a
40	84.00±5.16c	86.95±5.19a	70.18±3.32a
60	82.00±4.22c	85.49±7.14a	70.70±1.92a
80	52.00±6.33a	85.44±5.42a	68.17±4.19a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

2.3 Effect of temperature on developmental time and parasitization *A. hispinarum*

Parasitization by *A. hispinarum* was effective from 22°C to 28°C. No development was observed at 31°C. The percentage of parasitization was not significantly different among temperatures tested. The percentage of parasitoid emergence of mummified larvae was significantly different, the highest was at 25°C (84.63%). The percentage of female parasitoid emergence and number of eggs from virgin female parasitoid were not significantly different among the treatments (Table 12).

Developmental time of the parasitoid from egg to adult decreased significantly with increase in temperature, ranging from 16.5 day at 28^{o}C to 23.8 day at 22^{o}C. There were significant differences in the rate of development among the temperatures tested for all life stages of *A. hispinarum*. Overall, *A. hispinarum* development from egg to adult was significantly more rapid at 28^{o}C than at the other temperatures tested (Table 13).

Table 12 Effect of temperature at 80±5% with relative humidity on percentage of parasitization, percentage of parasitoid emergence, percentage of female parasitoid and number of eggs from virgin female parasitoid at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007.

Temperature (^{o}C)	% Parasitization	% Parasitoid emergence	% Female	No. of eggs from virgin female parasitoid
22	79.5±5.50a	77.79±6.69b	67.99±8.87a	42.60±13.39a
25	84.5±5.99a	84.63±3.84a	71.12±3.59a	43.75±14.04a
28	81.5±6.26a	65.69±3.99c	68.91±6.17a	41.20±12.36a
31	-	-	-	-

Note: (-) Not complete in its development.

Means followed by the same letters in a column are not significantly different at 5% level by Tukey’s multiple range tests.

Table 13 Effect of temperatures on life stage of *Asecodes hispinarum* Bouček in relation to temperature (^oC) reared on *Brontispa longissima* Gestro at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007.

Temperature (^oC)	Developmental Time (days) of parasitoid				Egg to adult (days)
	Egg	Larval	Prepupal	Pupal	
22	5.3±0.48c	7.7±0.48b	11.04±0.71c	14.0±0.94c	23.8±0.42c
25	3.2±0.42b	6.8±0.42a	10.20±0.42b	12.2±0.42b	19.6±0.52b
28	2.2±0.42a	6.6±0.52a	7.10±0.74a	9.6±0.70a	16.5±0.53a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

2.4 Host age preference and their effect on parasitization, parasitoid emergence, percentage of female *A. hispinarum* emergence and number of eggs from virgin female parasitoid

2.4.1 No-choice test

In a no-choice study, the results show that all larval instars of *B. longissima* were susceptible to parasitism by *A. hispinarum*. This experiment also showed that *A. hispinarum* attacked the fourth instar larvae more frequently than for the other host stage. The percentage of parasitization was significantly lowest (58.00%) in the first instar. Percentage of parasitoid emergence was increased significantly in the older instars, but this percentage of female parasitoid emergence was similar in all host stages, whereas total number of eggs form virgin female parasitoid varied with host age; with first instar larvae yielding the lowest number followed by the fourth instar larvae (Table 14). Males were similarly smaller than females from the same host instar. The body length of male and female at fourth instar were biggest. The body length of male was 0.82 mm. and female was 0.93 mm. The length of right forewing of both males and females were 0.57 mm. and 0.68 mm. (Table 15).

2.4.2 Choice test

A. hispinarum successfully attacked and developed in all larval instars (Figure 37). The development time from egg to adult was not different among the host instars, taking from 17 to 20 days. In the choice of experiment, *A. hispinarum* prefered the fourth instar reflecting in the highest percentage of parasitization (85.00 %). The percentage of parasitoid emergence from the first instars was significantly lower (55.00 %). Percentage of female parasitoid emergence from mummified larvae was similar in all host stages, but total number of eggs form virgin female parasitoid found in each adult female was significantly different (Table 16). In the case of the first instars larvae, the lowest number of eggs per female was 25.05±7.66 eggs. Males were always smaller than females from the same host instar. The body length of male and female at fourth instar were biggest the results were similar to in no choice test (Table 17).

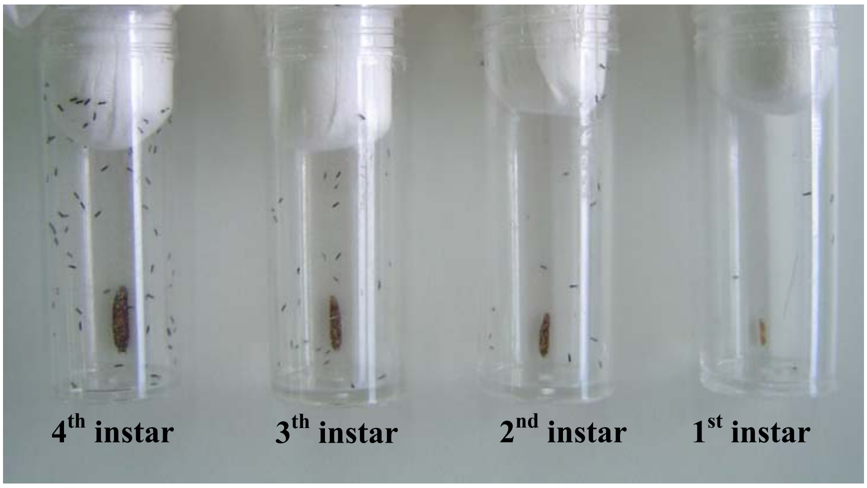

Figure 37 Mummified larvae placed in individual tubes with each instar of *Asecodes hispinarum* Bouček for parasitoid emergence.

Table 14 Effects of different larval stages of *Brontispa longissima* Gestro on parasitization by female of *Asecodes hispinarum* Bouček in no choice experiment at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007.

Larval instar of host	*n*	% Parasitization	% Parasitoid emergence	*n*	% Female	No. of eggs from virgin female parasitoid
First	10	58.00±7.89a	56.47±13.15a	20	67.09±11.28a	23.65±6.93a
Second	10	79.00±8.43b	68.19±14.06ab	20	65.14±12.43a	34.95±14.97b
Third	10	83.00±10.85b	78.15±5.51bc	20	68.91±5.71a	36.65±15.39b
Fourth	10	88.00 ±5.37b	81.84±7.36c	20	69.82±6.08a	40.85±13.97b

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

Table 15 Effect of different larval stages of *Brontispa longgissima* Gestro on body length and length of forewing of *Asecodes hispinarum* Bouček in no choice experiment at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007 (n = 20).

Larval instar of host	Body length (mm.) of parasitoid		Length of right forewing (mm.) of parasitoid	
	Male	Female	Male	Female
First	0.67±0.01a	0.70±0.07a	0.47±0.01a	0.49±0.02a
Second	0.71±0.02b	0.74±0.01b	0.49±0.01b	0.52±0.02b
Third	0.79±0.05c	0.86±0.03c	0.53±0.02c	0.62±0.02c
Fourth	0.82±0.02d	0.93±0.03d	0.57±0.02d	0.68±0.01d

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

Table 16 Effects of different larval stages of *Brontispa longissima* Gestro on parasitization by female of *Asecodes hispinarum* Bouček in a choice experiment at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007.

Larval instar of host	*n*	% Parasitization	% Parasitoid emergence	*n*	% Female	No. of eggs from virgin female parasitoid
First	10	55.00±8.51a	53.80±16.01a	20	65.66±12.54a	25.05±7.66a
Second	10	64.00±8.43b	68.20±10.64b	20	65.79±10.03a	32.10±14.01ab
Third	10	74.00±10.75c	69.30±12.40c	20	68.44±6.71a	37.80±12.99bc
Fourth	10	85.00±5.27d	75.60±5.97d	20	69.62±4.19a	43.55±15.07c

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

Table 17 Effect of different larval stages of *Brontispa longgissima* Gestro on body length and length of forewing of *Asecodes hispinarum* Bouček in a choice experiment at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007 (n = 20).

Larval instar of host	Body length (mm.) of parasitoid		Length of right forewing (mm.) of parasitoid	
	Male	Female	Male	Female
First	0.67±0.01a	0.69±0.06a	0.47±0.01a	0.49±0.02a
Second	0.72±0.01b	0.73±0.03b	0.50±0.00b	0.53±0.02b
Third	0.78±0.05c	0.84±0.03c	0.54±0.01c	0.60±0.05c
Fourth	0.82±0.06d	0.93±0.03d	0.59±0.02d	0.69±0.01d

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

2.5 Effect of alternative host plant of *B. longissima* on parasitization, parasitoid emergence, percentage of female *A. hispinarum* emergence and number of eggs from virgin female parasitoid

2.5.1 No-choice test

The parasitoids successfully completed their life cycles in *B. longissima* larvae fed on coconut, *Cocos nucifera* and typhus, *Typha angustifolia* L. leaves. The developmental period of *A. hispinarum* parasitization of larvae *B. longissima* fed on *C. nucifera* and *T. angustifolia* were not significantly different in the no-choice tests, taking about 18 to 20 days. The percentage of parasitization, percentage of parasitoid emergence, percentage of female parasitoid emergence and number of eggs from virgin female parasitoid were not significantly different (Table 18).

2.5.2 Choice test

In the choice test, the result was similar to the no-choice test. The percentage of parasitization, percentage of parasitoid emergence, percentage of female parasitoid emergence and number of eggs from virgin female parasitoid were not significantly different. The result showed that the qualities of mummified larvae were not different (Table 19), (Figure 38).

Table 18 Effect of host plants feeding by *Brontispa longissima* Gestro on percentage of parasitization and percentage of parasitoid emergence of *Asecodes hispinarum* Bouček at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007 (*n*=10).

Host	No-choice		Choice	
	% Parasitization	% Parasitoid emergence	% Parasitization	% Parasitoid emergence
Cocos nucifera	84.00±5.16a	82.74±5.02a	78.00±7.89a	74.30±5.96 %a
Typha angustifolia	84.50±5.50a	84.78±9.11a	80.00±8.16a	73.79±6.02 %a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

Table 19 Effect of host plants feeding by *Brontispa longissima* Gestro on percentage of female parasitoid and number of eggs from virgin female parasitoid of *Asecodes hispinarum* Bouček at the Plant Protection Research and Development Office, Department of Agriculture, Bangkok, 2007 (*n*=20).

Host	No-choice		Choice	
	% Female	No. of eggs from virgin female parasitoid	% Female	No. of eggs from virgin female parasitoid
Cocos nucifera	69.66±4.50a	42.95±11.98a	63.65±7.81a	46.60±10.92a
Typha angustifolia	71.04±4.48a	47.55±11.01a	65.28±4.16a	44.70±14.85a

Means followed by the same letters in a column are not significantly different at 5% level by Tukey's multiple range tests.

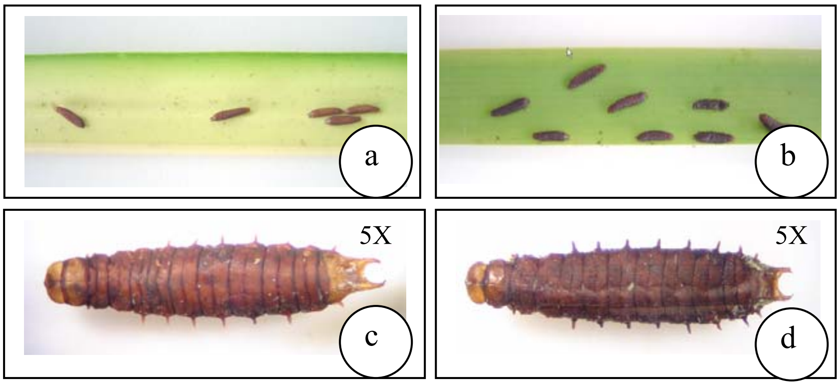

Figure 38 Mummified larvae rearing on different species of palm.

a) Mummified larvae on coconut leaves.

b) Mummified larvae on typhus leaves.

c) Mummified larvae rearing from coconut leaves.

d) Mummified larvae rearing from typhus leaves.

Part 3 Pest management program for major insect pests of coconut in a golf course

3.1 Control of coconut hispine beetle, *Brontispa longissima* Gestro

3.1.1 Observation of damage of coconut leaves 1st-10th leaves

The rapid survey by grading the damage of *B. longissima* from every tree in the area showed that the intensity of damage was quite high during February to May and gradually decreased from June to December (Figure 39). The highest and lowest overall damages (A+B+C+D) were 64.85 and 33.76% in May and December, respectively while the average damage for the whole year was 48.00%. The severe leaf damage level (Grade D = 76-100%) reduced to 0.26% in December. The result of control was witnessed by the new coconut leaves to be fresh with less damage.

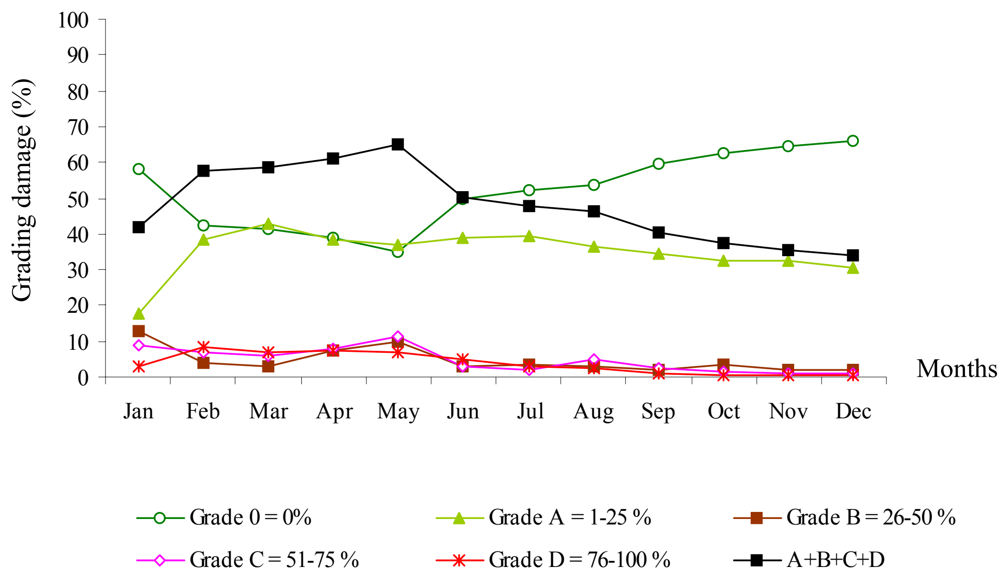

Figure 39 Grading damage of the first ten leaves of coconut palm by *Brontispa longisssima* Gestro at Panya Indra golf course, Bangkok during January to December 2007.

3.1.2 Damage levels of newly opened leaves

Monthly grading of newly opened leaf damage carried out for one year revealed that the combined damage (A+B+C+D) ranged from 34.67-66.67% with an average of 45.75% (Figure 40). Most damage occurred at Grade A (11.22-38.50%). The highest and lowest damage levels in July and December were 67.33 and 34.67%, respectively. Monthly absolute counting damage levels of newly opened leaves observations carried out for one year.

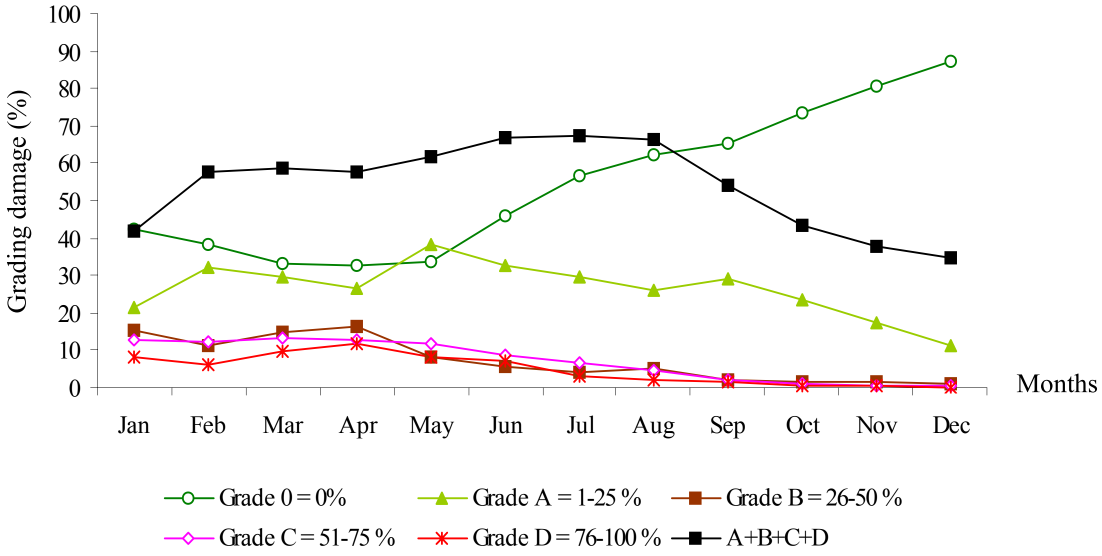

Figure 40 Grading damage of newly opened leaves of coconut by *Brontispa longisssima* Gestro at Panya Indra golf course, Bangkok during January to December 2007.

3.1.3 Population study of *B. longissima*

The buildup of *B. longissima* population commenced from February then dropped to relatively low level in March, sharply increased in April and reached its peak in June (Figure 41). Thereafter, it declined and reached the lowest level in December. The highest egg number occurred in May (35.65 eggs) while the highest larval and pupal numbers were found in June (90.58 larvae) and May (3.23 pupae), respectively. The adult population was also highest in May (31.64 adults). Population density of *B. longissima* became at low level nine months after initial parasitoid release.

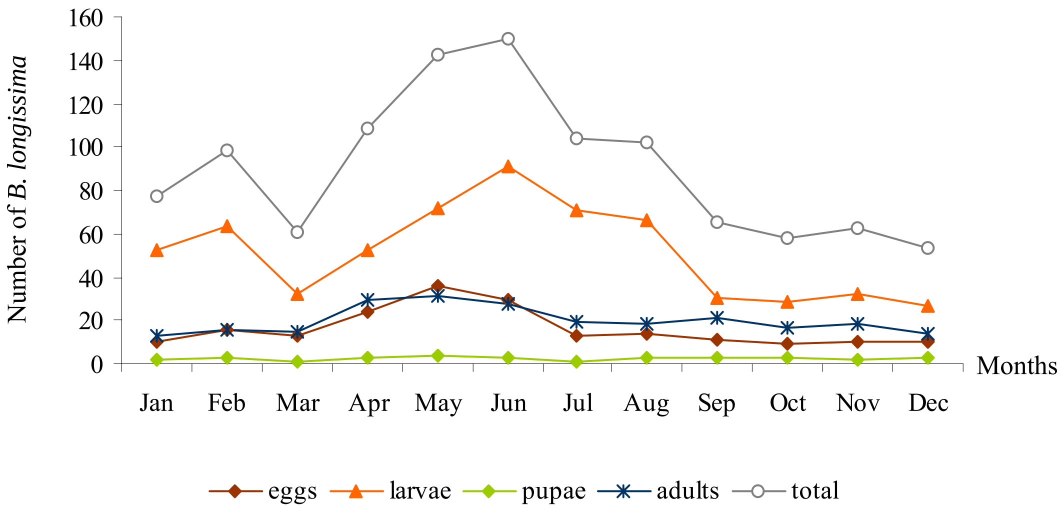

Figure 41 Population dynamics of coconut hispine beetle, *Brontispa longissima* Gestro per spear from 20 selected infested spears at Panya Indra golf course, Bangkok during January to December 2007.

3.1.4 Release of parasitoids in the field

The release of parasitoids was based on density of coconut damage. The average damage in Panya Indra golf course at the beginning of this study was 48.00% with the total damage area of 43 rai. Mummified larvae containing parasitoids were released at an average of 246 mummies per month totaling 2,950 mummies during January to December, 2007 (Table 20). *A. hispinarum* were first retrieved from the field in June (5 months after release) when rate of field parasitization was 13.48% (Table 21). Thereafter, the mummified hosts with *A. hispinarum* were found in August and November with parasitization rates of 8.58 and 14.08%, respectively. The trees showed clear signs of recovery with green shoots (Figure 42).

Table 20 Methodology for mummified larvae of *Asecodes hispinarum* Bouček releasing to control *Brontispa longissima* Gestro in Panya Indra golf course, Bangkok during January to December 2007.

Months	% Damage (A+B+C+D)	Number of coconut damage (trees)	Area of damage (rai)	Calculated mummies for release	Actual released mummies
January	42.02	756	38	190	200
February	57.6	1,037	52	260	300
March	58.44	1,052	53	265	300
April	61.28	1,103	55	275	300
May	64.85	1,167	58	290	300
June	50.14	903	45	225	250
July	47.85	861	43	215	250
August	46.54	838	42	210	250
September	40.22	724	36	180	200
October	37.64	678	34	170	200
November	35.68	642	32	160	200
December	33.76	608	30	150	200
Avg.	48	864	43	215	246

Table 21 Parasitization on population *Brontispa longissima* Gestro by 20 randomly selected infested spear leaves of coconut palms at Panya Indra golf course, Bangkok during January to December 2007.

Months	No. of *B. longissima*/spear		The percentage of parasitization[1]
	Larvae	Mummified larvae	
January	12.55	0	0
February	13.65	0	0
March	11.2	0	0
April	28.9	0	0
May	31.2	0	0
June	22.25	3	13.48
July	11.3	0	0
August	23.3	2	8.58
September	10.15	0	0
October	6.3	0	0
November	14.2	2	14.08
December	12.15	0	0

[1] Parasitization (%) = $\frac{\text{No. of mummified larvae}}{\text{No. of larvae}} \times 100$

Figure 42 Change of leaf damaged on the coconut palm after released *Asecodes hispinarum* Bouček.

3.2 Control of red palm weevil, *Rhynchophorus ferrugineus* Oliver

The data was collected for 12 months, from April 2007 to March 2008. The cutting off of coconut trees from infestation of red palm weevil occurred to 21 trees (Figure 43). The infested coconut palm was highest in April. After the analysis was done, the coconut trees infested by red palm weevil were less. The number of infected trees was eliminated at the end of the program. The average of infested trees was 1.17%. For control by ten pheromone traps, the results showed that the pheromone traps could catch the beetles (Figure 44). A total 26 beetles were caught; the numbers of male and female caught were 8 and 18 beetles, respectively. The numbers of beetle caught highest was in August (Figure 45). The number of females caught was more than male beetles. The average mean number of beetles caught per trap per month ranged from 0 to 0.3 (Table 22).

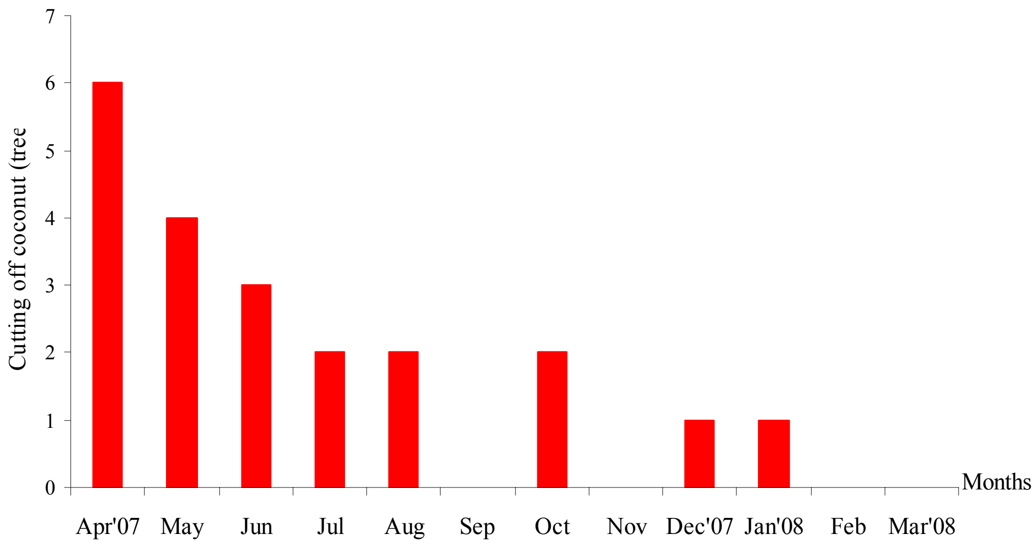

Figure 43 Number of cutting off of coconut trees from infestation of *Rhynchophorus ferrugineus* Oliver from April 2007 to March 2008 at Panya Indra golf course, Bangkok.

Figure 44 Pheromone traps control *Rhynchophorus ferrugineus* Oliver.

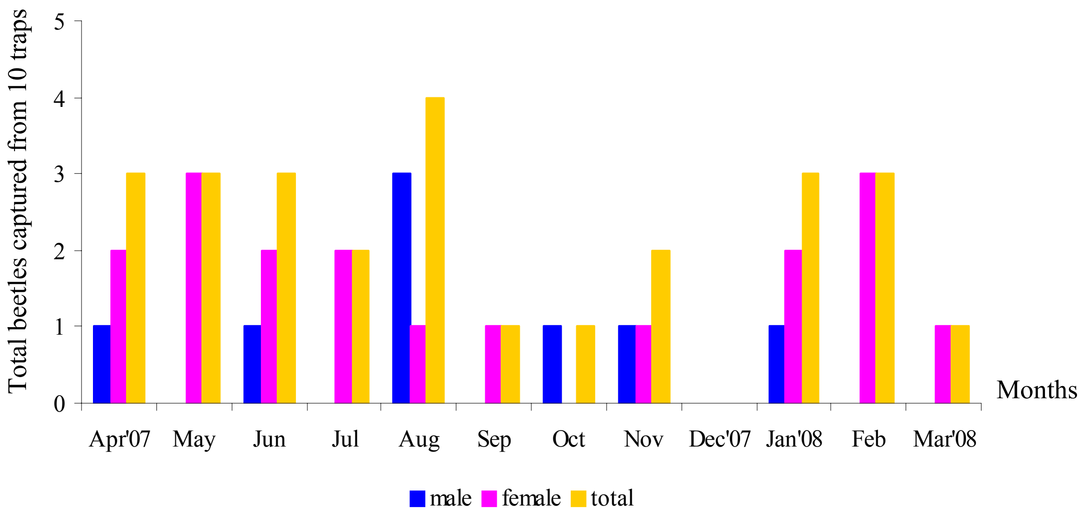

Figure 45 Total number of *Rhynchophorus ferrugineus* Oliver caught in 10 pheromone traps at Panya Indra golf course, during April 2007-March 2008.

Table 22 Capture rates of *Rhynchophorus ferrugineus* Oliver beetles per pheromone traps per months during April 2007 to March 2008 at Panya Indra golf course, Bangkok.

Months	No. of red palm weevil per pheromone trap	
	Male	Female
April'07	0.1	0.2
May	0.0	0.3
June	0.1	0.2
July	0.0	0.2
August	0.3	0.1
September	0.0	0.1
October	0.1	0.0
November	0.1	0.1
December'07	0.0	0.0
January'08	0.1	0.2
February	0.0	0.3
March'08	0.0	0.1
Avg.	0.07	0.15

3.3 Control of rhinoceros beetle, *Oryctes rhinoceros* L.

The data collected for 12 months, showed results that the pheromone trap could catch the beetles (Figure 47). A total of 718 beetles were caught with an average 58.9 beetles per month; the numbers of male and female caught were 130 beetles and 588 beetles, respectively. The number of females caught was more than males. The numbers of beetles caught the most was 111 beetles in November and lowest 22 beetles in June (Figure 46). The mean number of beetles caught per trap per month ranged from 0.5 to 4.25 both male and female (Table 23). The number of males caught per month ranged from 3-21 and females from 16-90 beetles. The Rhinolures were effective for only three months and could be observed that the number of beetles per trap decreased. So after three months, new rhinolures were added to every trap. The location of areas traps in the field edge showed that a large amount rhinoceros beetle could be caught. Monthly observations carried out for one year in a coconut plantation at Panya Indra golf course revealed considerable variation in damage from month to month. The effect of *Metarhizium anisopliae* in manure pits (Figure 48), its maximum prevalence was in June-November, and the least was in March-April. The prevalence of fungus had a significant negative relationship with the high temperature and low humidity. The manure pits of the larvae of rhinoceros beetle were collected to check the percentage of infestation three times. In July percentages of infected larvae was highest 79.63% (Table 24). The intensity of percentage of leaves damage was more during September-November and less during June-August periods. The damage intensity varied from 9.12 to 12.65 percentage of leaves damage. The percentage of leaves damage was highest in November and lowest in July in 2007 (Figure 49). The destruction by rhinoceros beetle did not increase in the golf course but the control could not lessen on the percentage of leaves damage to a desirable level because the rhinoceros beetle could breed throughout the year.

Table 23 Capture rates of *Oryctes rhinoceros* L. beetles per pheromone traps per months during April 2007 to March 2008 at Panya Indra golf course, Bangkok.

Month	No. of rhinoceros beetle per pheromone trap	
	Male	Female
April'07	0.69	4.25
May	0.38	1.88
June	0.13	1.25
July	0.69	3.63
August	0.56	2.63
September	0.38	2.44
October	1.00	5.50
November	1.31	5.63
December'07	0.50	1.81
January'08	1.06	3.63
February	1.25	3.13
March'08	0.19	1.00
total	8.13	36.75

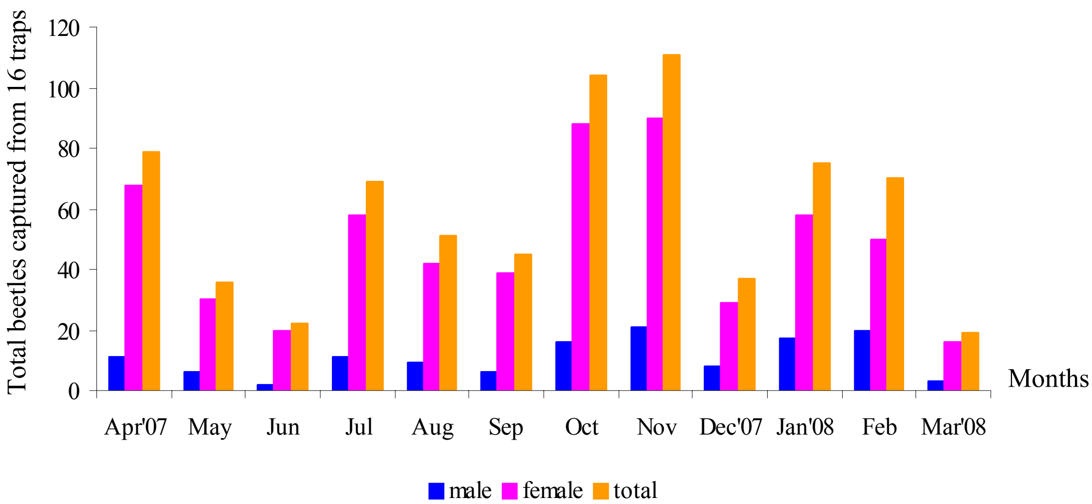

Figure 46 Total number of *Oryctes rhinoceros* L. caught in 16 pheromone traps at Panya Indra golf course, during April 2007 to March 2008.

Figure 47 SPALT-RB trap control *Oryctes rhinoceros* L.

Table 24 Percentage of infected on *Oryctes rhinoceros* L. in the manure pits after releasing the *Metarhizium anisopliae* at Panya Indra golf course, ten locations during April 2007 to March 2008.

Months	No. of collected larvae			% Infected larvae
	Uninfected	Infected	Total	
July	144	563	707	79.63
October	137	423	560	75.54
January	231	323	554	58.30
Avg.	170.67	436.33	607.00	71.16

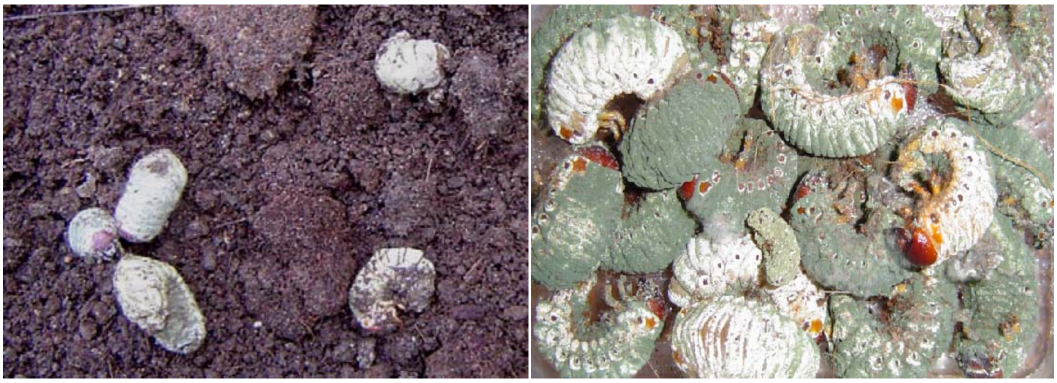

Figure 48 Larvae of rhinoceros beetle by using *Metarhizium anisopliae* (Metch) Sorock.

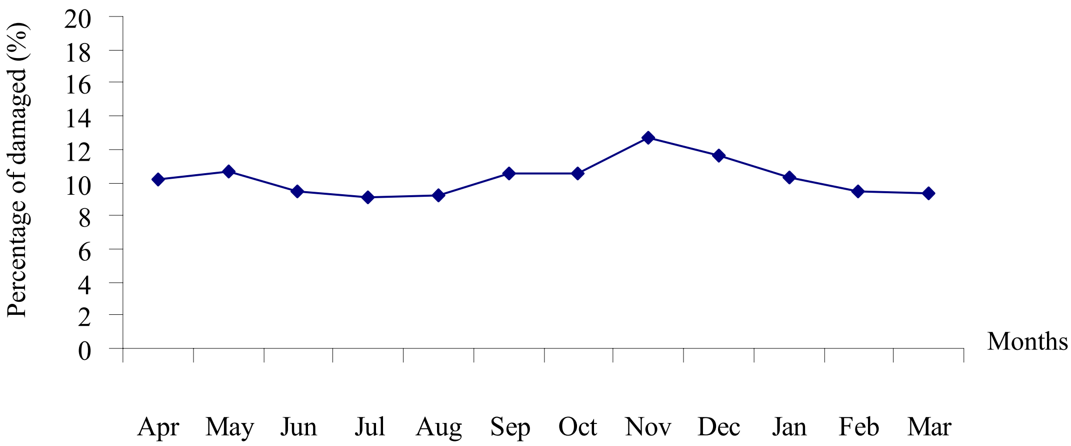

Figure 49 Percentage of leaves damage per month on coconut palms by *Oryctes rhinoceros* L. on 1,800 palms, at Panya Indra golf course, during April 2007 to March 2008.

DISCUSSION

Part 1 Mass rearing and biological study of *Asecodes hispinarum* Bouček

The temperature from 24^{o}C to 28^{o}C was suitable for development and reproduction of *Brontispa longissima* Gestro (Zhong *et al*., 2005). Cleanliness and hygiene are important in this method; decomposing leaf materials should be removed every two days to prevent the build up of moisture and pathogens and clean leaves before use by 10% Clorox®. The amount of leaves should be sufficient to provide an adequate food supply for the host, and maintain moisture, but should not be excessive, as too many leaves prevent adequate air circulation. This increases moisture levels, which promote the development of fungi and bacteria that will affect the quality of the leaves and encourage the growth of lethal pathogens (Liebregts *et al*., 2006). This method in this paper used 20 coconut leaves cutting per rearing box and individual developmental stages of *B. longissima* were kept separate. This method was similar to Liebregts *et al* (2006) who reported that under optimal rearing procedures, the individual developmental stages of *B. longissima* are kept separate to produce a maximum number of fourth instar larvae, and to make it easier to maintain the host culture. For rearing parasitoids, the method similar to Liebregts *et al* (2006) who reportedly placed approximately 20 *Brontispa* 4th instar larvae with several coconut leaf cuttings. The rearing boxes introduced some 60 newly emerged adult parasitoids.

The effect of temperature to adult longevity of *A. hispinarum* decreased when temperature increased. Adult survival was affected by temperature. The highest longevity for fed females 4.90 days and males 3.35 days was recorded at 22^{o}C. The lowest longevity for fed female 1.26 days and male 1.13 days was recorded at 31^{o}C. This was similar to Lu *et al* (2008) who reported that adult longevity of parasitoids decreased with increasing temperature, with mean longevity of 3.7 days at 16^{o}C and 1.3 day at 30^{o}C. In general, and usually in males as well as females, longevity decreases with increasing temperature within optimum range. Longevity is longer for females that have the opportunity to feed than on females with out food. The fed honey adults lived longer than fed water. The importance of sugar intake for the longevity, fecundity, and high attack rates of adult parasitoids is documented, among others (Powell, 1986). The average longevities of fed *A. hispinarum* females reported here at 22°C is higher (4.90 days) than *A. hispinarum* females without feeding anything (2.75 days).

After adult parasitoids emergence, they were mating and searching a host to parasitize the host larvae. This was similar to Liebregts *et al* (2006) who reported that the mating takes place shortly after the females emerge from the mummified larvae. Before oviposition, parasitoids searched for a suitable position on the host by probing movements with their ovipositors. Female parasitoids stood over host bodies and penetrated dorsal cuticles with their ovipositors to deposit eggs. In this paper, the parasitization was completed on an average of 36 min. at 25°C. Adult emergence occurred through holes chewed in the dorsum or abdomen cuticle of *B. longissima* by the adult parasitoids. Adult parasitoid emergence holes were made in 20-30 min., with most making 3-5 holes per mummified larvae (Lu *et al*., 2008).

Host specificity of the other studies were conducted by using larvae of flour beetle (*Tenebrio molitor*), coccinellid larvae (*Harmonia convergens*), common cutworm (*Spodotera litura*) and lacewing larvae (*Mallada basalis* and *Chrysoperla carnea*) as test hosts. The studies found that *A. hispinarum* did not attack the tested larvae. In conclusion of host specificity, it was safe for using *A. hispinarum* for the control of *B. longissima* in Thailand (Winotai *et al*., 2007). The host specificity study in this paper showed that *A. hispinarum* was not only a specific attack on *B. longissima* but it also attacked *Plesispa reichei* Chapuis as well. However, the qualities of mummified larvae of *B. longissima* were higher than *P. reichei*. The experiment in the field is necessary to conclude that *A. hispinarum* could be parasitized *P. reichei* in nature. This study suggests that *A. hispinarum* could be a biological agent of *B. longissima* and *P. reichei*.

The optimal temperature for fecundity was 24-28°C (Lu *et al*., 2008). The females laid an average of 49 eggs during its lifetime, with range of 20-77 eggs at 25°C. This was similar to Lu *et al* (2005) who reported that the fecundity per female was 43 eggs on average and the peak of oviposition occurred within 12 hrs after mating. The female of *A. hispinarum* can lay more than 100 eggs into one larva (Liebregts *et al*., 2006).

Part 2 Biological control study of *A. hispinarum* under laboratory condition

The optimal time for parasitization was more than 24 hrs. This was similar to Winotai *et al* (2007) who reported that the method for rearing of *A. hispinarum*, kept the parasitoids of *A. hispinarum* and the larvae of *B. longissima* in the container for three days.

The number of female parasitoids ranging from 10 to 80 females affected parasitization rate. Percentage of parasitization was highest at 40 and 60 females, so the optimal numbers of female parasitoids for parasitization were 40 and 60 females. This method was referred by Liebregts *et al* (2006) who reportedly introduced some 60 newly emerged adult parasitoids of *A. hispinarum* with 20 of *B. longissima* fourth instar larvae for rearing parasitoids. Introducing too large a number of parasitoids into a single box with limited hosts is not favorable. The percentage of parasitization was lowest with 80 added parasitoids. This was similar to Lu *et al* (2005) who reported that the parasitization efficiency of *A. hispinarum* decreased with the increasing of *A. hispinarum* density. As with many other laboratory reared insects, increased density caused greater mortality (Park, 1937).

The results indicate that *A. hispinarum* could be successfully developed between 22 and 28^{o}C. However, because the highest temperature examined was 31^{o}C, *A. hispinarum* could not complete its development. Developmental time of *A. hispinarum* decreased with increasing temperature up to 28^{o}C. This was similar to Tang *et al* (2007) who reported that the different combinations of temperature affect developmental time and longevity of *A. hispinarum*. These conditions should be taken into account when developing habitat manipulation tactics. Temperatures higher than 30^{o}C are lethal. However, *A. hispinarum* must be released in the early morning, shortly after sunrise, under a shady area. Releasing parasitoids around noon or in the early afternoon when it is hottest and driest, will have little chance of surviving (Liebregts *et al*., 2006). In referring to that, summer temperatures in some areas could negatively affect parasitoid development and survival. Results of this study show that high temperature has a huge impact on the mortality of adults. Differences in climate tolerance should be considered in the selection of natural enemy species for release (Hoelmer and Kirk, 2005).

A. hispinarum successfully attacked and developed in all larval of *B. longissima* instars. This was similar to Viet (2004) who reported that the female parasitoids of *A. hispinarum* can attack first instar to fourth instar larval stage. The suitable host stage, the female of parasitoids preferred to attack third and fourth instar larvae of *B. longissima* over other host stages. Percentage of parasitization and survival are lowest in first instar larvae. The studies first and second instar are less capable of withstanding parasitization. There is a general view that smaller hosts often yield smaller parasitoids with reduced longevity and fecundity (Vinson and Iwantsh, 1980).

A study on host plants of *B. longissima* found that the insect could developed and complete its life cycle on four tested plants, *Areca catechu, Nypa fruticans*, *Cargota smitis* and *Typha angustifolia*. Developmental periods of *B. longissima* fed on *T. angustifolia* were studied for the purpose of developing techniques for mass production of *B. longissima* larvae and mass rearing the parasitoid (Winotai *et al*., 2007). In referring to this study on the effect of alternate plant food of *B. longissima*, the larvae of *B. longissima* could be developed and complete its life cycle on *C. nucifera* and *T. angustifolia*. When lacking of coconut leaves, the leaves of *T. angustifolia* are the best one to replace *C. nucifera* and rear *B. longissima*. *T. angustifolia* is a cheap material and convenience to use which should be readily available in rural towns. This rearing of *A. hispinarum* technique is simple and can be applied by farmers, students and field workers after a training demonstration by experienced and trained research staff.

Part 3 Pest management program for major insect pests of coconut in a golf course

The control of coconut hispine beetle, *B. longissima* used sanitation and biological control. This was similar to Meldy *et al* (2004) who reported the coconut cultivation through sanitation and use of recommended fertilizer and application are needed to obtain more healthy palms and higher coconut production. The biological control has recently been recognized as a promising and effective tool in the management of the most important pest on coconut palm (Sathiamma *et al*., 2001). The larval parasitoid, *A. hispinarum* was one of the mosts successful species to control *B. longissima* (FAO, 2004). This was similar to Voegele (1989) report that *Asecodes* sp. was the dominant parasitoid in the field, being present in 37% of the samples. In this study, the mummified larvae of *A. hispinarum* were collected in June after the release of parasitoids five months later. The percentage of parasitization in the field was 13.48%. This was similar to Voegele (1989) who reported that the release program, *Asecodes* certainly has to be considered a very valuable enemy of *B. longissima*. Following confirmation of the establishment of *A. hispinarum* in the field, mummified larvae were found five months after they were released in January. The trees showed clear signs of recovery with green shoots. This was similar to Guo (2005) who reported that a primary survey the population of the *B. longissima* decreased 5-6 months later. For a successfully established biological control program, the pest never exceeds economic injury levels. If the pest population starts to increase, the biological control agent increases and reduces the pest population growth rate in a density dependent fashion (Robert *et al*., 2003). Now more and more evidence indicates that the successful release of the parasitoid depends on lots of environmental factors, such as the temperature, humidity, environment, pesticide used by the farmer, wind and so on. The need for continued releases of the parasitoid was done continuously because additional numbers of parasitoids in the field does not significantly contribute to increasing the natural population. The continuation of laboratory cultures for mass rearing of the parasitoid and *B. longissima* therefore utilizes staff, infrastructural resources and funds that could be put to better use in controlling. Biological control by using parasitoids is more effective during wet season or in cool areas because it requires free water and nectar. During a dry season or in dry areas, it is difficult to rear the parasitoids as the lower relative humidity hardens the skin of the mummified larvae, which affects the successful emergence of the parasitoids (FAO, 2004).

The red palm weevil, *Rhynchophorus ferrugineus* Oliver, is an economically important, tissue-boring pest of date palm in many parts of the world. Originating in Southern Asia and Melanesia, where it is a serious pest of coconuts, this weevil has been advancing westwards very rapidly since the mid 1980s (Gomez and Ferry, 1999). The results of the survey conducted to know the impact of trees from infestation of red palm weevil and use of the pheromone trap to control was done. The method was similar to Kaakeh *et al* (2001) who reported that the symptoms of red palm weevil infested were cut as soon as possible. The use of pheromones in monitoring and controlling red palm weevil populations has become an important tool of managing this pest. The cutting off of damaged coconut tress occurred on 21 trees. The numbers of beetles caught highest were in August. Both sexes were attracted to traps, the higher number of females than males in the traps may be due to that females may disperse more than males in order to find a suitable food source for their progeny. Also, the aggregation pheromone released from males may have attracted females more than males. In addition, IPM program for the red palm weevil should be implemented using a pheromone trapping system. Red palm weevil is also important for the development of pheromone application in controlling the destructive pest. Infestation by rhinoceros beetle is severe in plantations where field hygiene and sanitation are poor (Kaakeh *et al*., 2001).

To manage the rhinoceros beetle, *Oryctes rhinoceros* L., ISCA Technologies and Phero Asia have collaborated to develop a new and improved lure. The SPLAT-RB lure emitions environmentally friendly. The SPLAT-RB was an aggregation pheromone in a consistent and long lasting rate, which attracted and traped the rhinoceros beetle at the bottom of the bucket trap. Unlike insect sex pheromones which attract only males of a species, aggregation pheromones attract both sexes of a species. Pheromone trapping is one component of an overall management plan in oil palm plantations where *Oryctes* is a problem. Trapping reduces populations of damaging beetles in the current population as well as in succeeding generations due to the prevention of egg laying (Loring, 2007). Newly-designed vane traps were more effective in capturing rhinoceros beetle than were barrier or pitfall traps. Traps were suspended 2-3 meters above ground. The results indicated a potential for using ethyl 4-methyloctate in operational programs to control rhinoceros beetle in oil palm plantations (Hallett *et al.*, 1995). The pheromone could catch females more than males. Biological control of the rhinoceros beetle is the most important component of the IPM package. In this experiment Rhinolures were effective for three months. This was similar to Nirula *et al* (1955) who reported that the effective period of release varied from 3 to 8 months, with an average of 5 months. The variation occurred probably as a direct result of fluctuating temperatures during the day. The green muscardine fungus, *Metarhizium anisopliae*, is a pathogen which kills the pest in conditions of low temperature and high humidity. Proper disposal of breeding grounds and field sanitation are important steps in IPM of *Oryctes*. The fungus was more effective in infected areas during the monsoon period. In this study, the manure pits were collected the larvae of rhinoceros beetle to check the percentage of infestation three times. In July, percentages of infected larvae were highest 79.63%. Under the IPM programme for the coconut rhinoceros beetle in the Pacific Island, Zelazny *et al*. (1985) had envisaged: Treatment of breeding places of the beetle with the entomopathogen *M. anisopliae*. To sum up, maintenance of field sanitation, extraction of beetles during the peak period of pest abundance on the breeding sites and re-release of *M. anisopliae* in manure pits are some of the methods which can be adopted for the efficient management of rhinoceros beetle. The results of the studies revealed that the pheromone traps and *M. anisopliae* can be very well incorporated in the IPM programme for rhinoceros beetle.

Integrated Pest Management (IPM) is an important component of sustainable agriculture. Though IPM concept is not new it is seldom implemented in full measure over a large area. The principle lays in the scientific integration of all possible pest management strategies in a harmonious manner. The main criteria have been the scouting for best population assessment and adoption of Economic Threshold Levels

(ET). Of late, concepts biologically intensive IPM or bio-intensive IPM is being recommended involving host plant resistance, biological control, use of pesticides like semiochemicals, cultural control, etc. are promoted (Jayaraj and Ignacimuthu, 2005).

CONCLUSION

The investigation on biology of *Asecodes hispinarum* Bouček revealed that the survival was longest at 22°C and shortest at 31°C. The highest survival for fed females were 4.90 days**,** and males were 3.35 days was recorded at 22°C. The time of oviposition attempt by *A. hispinarum* on larvae of *Brontispa longissima* Gestro was 35.88 minutes. The percentage of female parasitoid was 60.72%. The larva of *A. hispinarum* ate inside the host larva until adult emerged. The adult of *A. hispinarum* came out from the host larva by making an emergence hole. Host specificity tested, it was first found that the *A. hispinarum* parasitized the other larvae of *B. longissima*. The result showed that *A. hispinarum* could parasitize *Plesispa reichei* Chapuis. However, the qualities of mummified larvae of *B. longissima* were higher than *P. reichei*. The females of *A. hispinarum* laid an average of 49.39 eggs during its lifetime, with a range of 20-77 eggs. For the mass rearing of *A. hispinarum*, 40 and 60 female parasitoids per 20 larvae of *B. longssima*, were used. The time for parasitization took place within 24 hrs before they were removed. Parasitization by *A. hispinarum* was effective from 22°C to 28°C. No development was observed at 31°C. The optimal temperature for rearing of *A. hispinarum* was at 25°C. *A. hispinarum* successfully attacked and developed in all larval instars of *B. longissima*, female parasitoids prefer third and fourth instar. Studies on the effect of alternate plant food of *B. longissima* that the larvae of *B. longissima* could develop and complete life cycle on *Cocos nucifera* L. and *Typha angustifolia* L. When testing the larvae feeding on coconut and typhus leaves for rearing *A. hispinarum*, the result showed that the qualities of mummified larvae are not different. This information has been useful because of the mass rearing product of mummified larvae.

The control of *B. longissima* was used by parasitoid of *A. hispinarum*. The mummified larvae released, averaged 246 mummies per month. The damaged leaves by *B. longissima* were observed on the 1^{st}-10^{th} leaves. The intensity of damage was more during February to May and came down after June to December. The highest damage level of *B. longissima* in May 64.85%, and lowest damage level in December 33.76%. When the entire monthly absolute counting damage levels of newly opened leaves were observed, the percentage of damage levels averaged 45.75%. The intensity of damage was more during January to May and came down after June to December. The high population was observed during the period from April to August and low from September to December. The build up of the population commenced from February, gradually increased and reached its peak in June. The adults of populations were high in May. The mummified larvae of *A. hispinarum* were collected in June after releasing parasitoids five months. The percentage of parasitization in the field was 13.48%. Thereafter, the mummified larvae of *A. hispinarum* were found in August and November, the percentage of parasitization was 8.58% and 14.08%, respectively. The result showed that the parasitoid could be established in the field. For the control of red palm weevil, *Rhynchophorus ferrugineus* Oliver, cutting off of damaged coconut trees for eliminatation of red palm weevil. The red palm weevil is a tissue borer pest of the coconut palm. The pest infestation is difficult to detect. Even though the trees were eliminated, the adult of *R. ferrugineus* could be caught every month. Pheromone trap caught the highest in August. The number of female caught was more than males. After control by sanitation and pheromone trap the red palm weevil did not spread in the golf course. For control of rhinoceros beetle, *Oryctes rhinoceros* L., the methods used pheromone trap and entomopathogenic fungi (*Metarhizium anisopliae*). In the pheromone trap, the number of females caught was more than males. The numbers of beetle caught were highest in November and lowest in June. The trap location areas in the field edge showed that a large amount rhinoceros beetle could be caught, because there were many breeding sites in this area. The effect of *M. anisopliae* in manure pits, had its maximum prevalence from June to November, and the least was in March to April. The percentage of leaves damage was highest in November and lowest in July. The destruction by rhinoceros beetle did not increase in the golf course but the control could not be brought down to the desirable level because the rhinoceros beetle could breed throughout the year and the breeding site (garbage heap) at field edge could not be controlled. The traps were recommended for placement one trap per two hectares (Loring, 2007). This experiment used 16 traps for 80 ha.; less than 24 traps for optimal results. The problem for trapping was the beauty in the golf course. For future control, which could result in its suitability and sanitation, pheromone traps added around the golf course is of utmost importance. The control of major insect pests of coconut palms was not successfully managed because the progarme had short too time period. Therefore the studies on pest mangement program for a longer period may yield a realistic picture of the control of maybe two to three years.

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APPENDIX

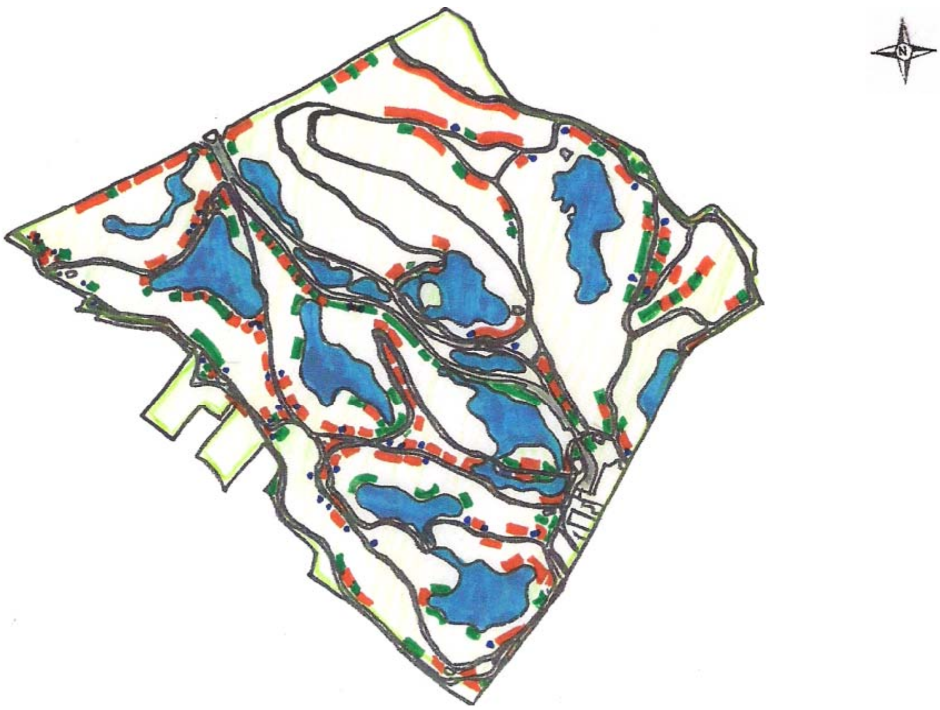
Remark:

Pheromone traps of *Oryctes rhinoceros* L.

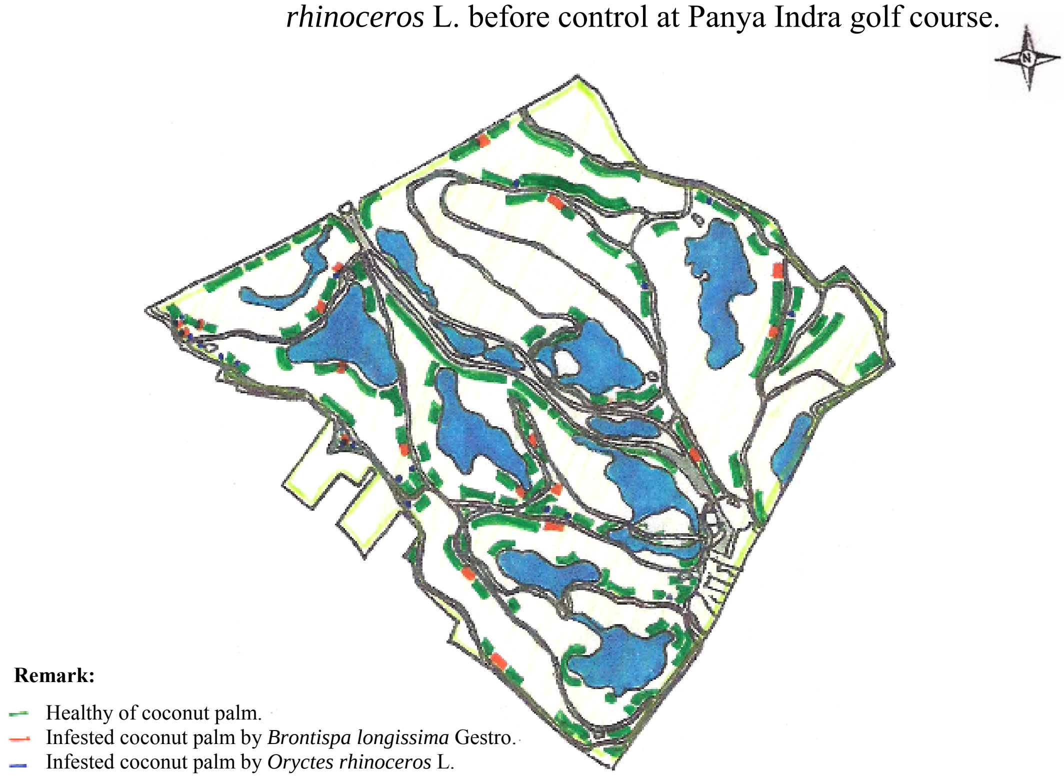
Pheromone traps of *Rhynchophorus ferrugineus* Oliver.

Manure pits for control of *Oryctes rhinoceros* L.

Appendix Figure 1 Locations of pheromone traps and manure pits.



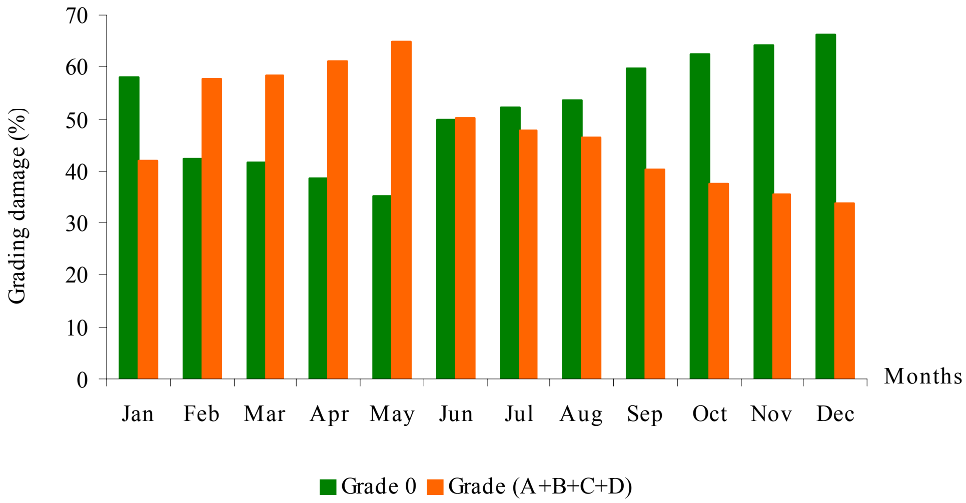
Appendix Figure 2 Distribution of *Brontispa longissima* Gestro and *Oryctes rhinoceros* L. before control at Panya Indra golf course.



Appendix Figure 3 Distribution of *Brontispa longissima* Gestro and *Oryctes rhinoceros* L. after control at Panya Indra golf course.

Appendix Table 1 Percentage of damage coconut leaves from 1st-10th leaves levels of coconut trees by *Brontispa longissima* Gestro evaluated at Panya Indra golf course, Bangkok during January to December 2007.

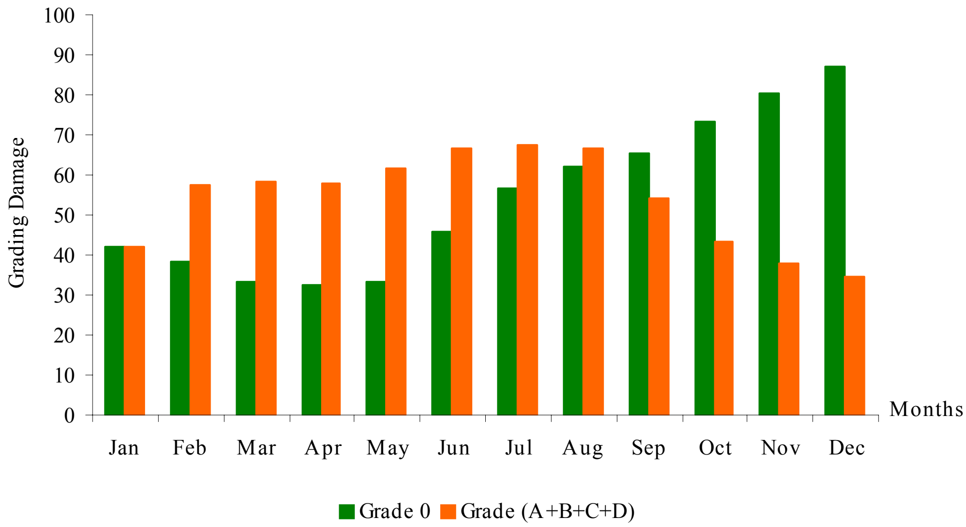
Months	Grade 0 0%	Grade A 1-25 %	Grade B 26-50 %	Grade C 51-75 %	Grade D 76-100 %	% Damage (A+B+C+D)
	The average of percentage of damaged leaves from first to ten leaves					
January	57.98	17.64	12.65	8.96	2.77	42.02
February	42.40	38.60	3.80	6.80	8.40	57.60
March	41.56	42.65	3.18	5.67	6.94	58.44
April	38.72	38.65	7.23	7.78	7.62	61.28
May	35.15	36.78	9.63	11.51	6.93	64.85
June	49.86	38.72	3.14	3.13	5.15	50.14
July	52.15	39.42	3.23	2.06	3.14	47.85
August	53.46	36.43	2.78	4.69	2.64	46.54
September	59.78	34.38	2.13	2.55	1.16	40.22
October	62.36	32.50	3.26	1.24	0.64	37.64
November	64.32	32.34	2.11	0.89	0.34	35.68
December	66.24	30.39	1.98	1.13	0.26	33.76
Avg.	52.00	34.88	4.59	4.70	3.83	48.00
Min.	35.15	17.64	1.98	0.89	0.26	33.76
Max.	66.24	42.65	12.65	11.51	8.40	64.85



Appendix Figure 4 Damage levels of coconut leaves 1st-10th leaves of coconut trees by *Brontispa longissima* Gestro evaluated at Panya Indra golf course, Bangkok during January to December 2007.

Appendix Table 2 Percentage of damage levels of newly opened leaves coconut trees by *Brontispa longissima* Gestro evaluated at Panya Indra golf course, Bangkok during January to December 2007.

Months	The average of percentage of damage levels of newly opened leaves					% Damage (A+B+C+D)
	Grade 0 0%	Grade A 1-25 %	Grade B 26-50 %	Grade C 51-75 %	Grade D 76-100 %	
January	42.22	21.39	15.5	12.72	8.17	42.02
February	38.28	32.00	11.22	12.17	6.33	57.60
March	33.33	29.39	14.56	13.16	9.56	58.44
April	32.67	26.44	16.22	13.00	11.67	57.78
May	33.44	38.50	8.22	11.51	8.33	61.72
June	45.72	32.67	5.67	8.61	7.33	66.67
July	56.72	29.56	4.22	6.39	3.11	67.33
August	62.17	26.11	5.11	4.67	1.94	66.56
September	65.33	28.89	2.22	1.95	1.61	54.28
October	73.28	23.72	1.39	1.05	0.56	43.28
November	80.61	17.33	1.33	0.44	0.29	37.83
December	87.22	11.22	1.11	0.33	0.12	34.67
Avg.	54.25	26.44	7.23	7.17	4.91	45.75



Appendix Figure 5 Damage levels of newly opened leaves coconut trees by *Brontispa longissima* Gestro evaluated at Panya Indra golf course, Bangkok during January to December 2007.

Appendix Table 3 Population dynamics of coconut hispine beetle, *Brontispa longissima* Gestro per spear from 20 selected infested spear leaves at Panya Indra golf course, Bangkok during January to December 2007.

Months	The average number of *B. logissima* per spear				total
	eggs	larvae	pupae	adults	
January	10.35	52.48	2.13	12.65	77.61
February	15.98	63.44	2.87	15.98	98.27
March	12.68	32.14	1.34	14.43	60.59
April	24.26	52.34	2.66	29.45	108.71
May	35.65	72.34	3.23	31.64	142.86
June	29.22	90.58	2.53	27.45	149.78
July	12.56	70.63	1.24	19.72	104.15
August	14.11	66.54	3.21	18.62	102.48
September	11.12	30.72	2.45	21.12	65.41
October	9.25	28.69	3.11	16.54	57.59
November	10.14	32.36	1.48	18.21	62.19
December	10.23	26.74	2.42	14.11	53.50
Avg.	16.30	51.58	2.39	19.99	90.26

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